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Topological Network Inversion Method of Fire Source Location for Liquefied Natural Gas (LNG) Storage

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Abstract

Liquefied Natural Gas (LNG) tank fire and explosion accident consequences and losses are very serious. Accident inversion method can provide the basis for accident prevention, but there are still some problems on the LNG tank fire with inversion method. Therefore, the topological network model and inversion method of LNG tank fire accident are proposed in this thesis. Firstly, the topology model of LNG tank fire inversion is established, and the optimal estimator of the shortest path is proposed according to the weighted edge topological network structure, so as to determine the fire location. Case study is applied to a LNG tank farm. The results show that the position of the fire source obtained by the proposed method is the same as that of the actual accident, which proves the feasibility of the method and provides a basis for reducing the fire losses and preventing accidents of LNG.

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Keywords: LNG storage tank, fire, topological network model, accident inversion, optimal estimator

1. Introduction

With the global natural gas consumption increasing, liquefied natural gas (LNG, Liquefied Natural Gas) tank fire and explosion accidents frequency also increases, and the consequences and losses of LNG tank explosion accident is very serious [1]. The world's first cryogenic tank explosion happened in 1944, when a $2\times10^4 m^3$ liquefied natural gas tank in Cleveland was suddenly broken, leaked and detonated, and a fire broke out. 133 people were killed and more than 300 injured, with direct economic losses amounting to $8 million. The study of fire spread inversion in tank farm has great significance for fire extinguishing of tank fire. Once the fire in the tank farm is out of control, it will lead to the Domino effect, and cause a large number of LNG tanks around the fire tank to catch fire, which will lead to fire spreading in the tank farm [2]. If we can find the initial combustion tank and find the cause of its combustion, we may start from the source, analyze the cause of tank fire, and better analyze the fire accident of tank. It is of great significance to analyze the damage caused by tank fires, to prevent in advance, to minimize the fire losses of tanks and to analyze the solutions of tank fires more quickly and better.

Because of the continuous storage of LNG storage tanks and intensive storage, as well as huge capital investment, serious fire accidents have been paid attention to by the fire department. If the disaster occurs, the location of the fire source cannot be determined in time and accurately, and measures cannot be taken to eliminate the fire source. Because of the complexity and variety of the LNG tank fire, the scene of the accident is often seriously damaged and it is difficult to determine the location of the fire source accurately.

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Inversion methods are applied in many fields. In the simulation of water pollution accidents, the source identification and concentration distribution simulation of sudden water pollution accidents are realized by the inversion method. In the aspect of nuclear diffusion of nuclear accident [3], the source term inversion method is applied to modify the source terms and diffusion parameters in the model, which makes the calculation of diffusion model more consistent with the true diffusion. The inversion method is also using thermal infrared remote sensing [4] to inverse land surface temperature, seismic wave exploration [5], salt rock creep law [6] and other issues. There are applied to the tank accident process qualitative inversion, for example the burning explosion accident in a factory[7] in a place with a major tank storage tank, a detailed study of the cause of the accident and the accident analysis of the accident morphology, tank strength and failure form, finally to the entire process of the inversion. In the inverse problem of heat conduction [8], starting from the spontaneous combustion mechanism of oil tank, adopting the research method of finite element analysis, computer simulation and thermal inversion algorithm, puts forward the theoretical research methods of inverse heat conduction problem of the storage tank based on the detection of spontaneous combustion. The previously developed optimization method and an alternative method based on normal equations applied to nonlinear parameter estimation are compared to improve the accuracy of LNG storage models and credibility of predictions [9].

There are generally some disadvantages of inversion methods:

(1) Ill-posedness. Because of its existence, the original conditions in slight interference or error, the inversion result is likely to appear completely distorted or a strong shock, it is one of the biggest obstacles to the inverse problem for widely used in practical engineering, in order to eliminate the ill-posedness of the inevitable factors, domestic and foreign scholars continue to study methods for solving inverse new problems and other optimization algorithms.

(2) Large amount of calculation. The common inverse problem is solved with optimization algorithm of iterative computation, which is repeatedly solving a lot of positive problems, leads to long time consuming, practical difficulties, and low real-time output and so on. All these problems affect the inverse problem of application in engineering practice.

This thesis proposes an inversion method based on network topology model, and solve the difficult problem of the nodes accurately determine the location of the fire accidents of tank fire in LNG, and analyzed by actual case, find the original position of the source correctly, proved the feasibility and accuracy of the method.

2. Basic principles and algorithms

2.1. Inversion problem

In the process of development of human society, people are accustomed to "the cause to effect" of the causal relationship, and try to establish a qualitative description of causal relationship (positive problem) but rarely mentioned “the effect to cause" (inverse problem). The inverse problem is relative to positive problems [10]. According to the idea of J.B.Keller[11], if in the two problem, a problem of interpretation or processing involves or contains all or part of the knowledge about another problem, we say that one is positive problem, another is inverse problem. As for the positive problem given by a model, it is generally easy to understand and thus relatively simple. The inverse problem is generally difficult because it is to explore the unknown [12]. For example, various integral transforms and their inverse problems are mutually inversion. Again, if given a polynomial as Eq. (1).

$$p_n(x) = c_n x^n + c_{n\text{-}1} x^{n\text{-}1} + L + c_1 x + c_0 \tag{1}$$

The assignment of n+1 given point $x_0, x_1, \cdots, x_n, x_i \in R^1$ is a positive problem, and its inverse problem is the Lagrange interpolation problem. That is to say, given the n+1 group value (x_i, y_i), $i = 0,1,\cdots,n$, the coefficients c_i of the n order polynomial $p_n(x)$ are required to satisfy the interpolation conditions: $p_n(x_i) = y_i, i = 0,1,\cdots,n.$.

2.2. Dijkstra algorithm

Dijkstra algorithm [13] is a search algorithm of finding the shortest path, proposed by the Holland scientists. In order to record the best path trajectory, the advance of each node in the path is recorded, and the shortest path is found by backtracking. Dijkstra algorithm is a typical single source shortest path algorithm. It is used to calculate the shortest path of a node to all other nodes. The main feature is that the starting point is centered and extended outward until the end of the expansion. Dijkstra algorithm is a typical shortest path algorithm, having a detailed introduction in many professional courses as a basic content, such as data structure, graph theory, operations research, and so on. Note that the algorithm requires no negative edges in the graph.