ALGORITHMS OF THE MINIMUM SPANNING TREE IN GAS SUPPLY SYSTEMS

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Abstract. In this paper, a method for tracing gas networks using the Kruskal algorithm and the Steiner algorithm is considered. The result of the work of algorithms on the example of a bio meta network between agricultural enterprises located on the territory of the Belgorod region is demonstrated. The economic result is determined using Steiner's refinement algorithm.

At present, when designing gas supply systems, the actual task is to use automatic network tracing. Automatic tracing allows you to save time and money both for designing and building networks, as the task of automatic routing is to reduce the length of pipes [1].

The automatic trace process is divided into two phases: global tracing and detailed tracing. At the stage of global tracing, a preliminary route is created based on the unit cost of the pipe meter or the cost of its laying, as well as the total length of the entire route [2].

The purpose of this paper is to determine the economically feasible method of designing gas networks by comparing the result of automatic routing using the algorithms of Kruskal and Steiner.

To achieve this goal, it is necessary to adapt the algorithms and compare the total length.

The construction of the minimal spanning tree is solved by algorithmization and has two principal differences.

1. Construction without additional vertices:
   - Prima-Kraskal algorithm;
   - The Borovka algorithm;
   - Dijkstra's algorithm.
2. Construction with additional vertices:
   - Steiner trees (Euclidean plane);
   - Steiner trees (Rectangular plane);
   - Melzak's algorithm;
   - Cocaine's algorithm.

The Steiner algorithm for the Euclidean plane can find its application in gas supply by bio methane between agricultural enterprises or for tracing inter-settlement or magistral gas pipelines where there are no hard-coded security zones for laying, such as in a city.

The Steiner algorithm for a rectangular problem can be used for intra-quarter gas distribution networks, for which a rectangular topology is typical and the designation zones are rigidly identified.

E. Gilbert and H. Pollack showed that the Steiner tree can reduce the minimum spanning tree to 13.4% [3].

The Steiner algorithm has four properties:

1. The number of edges of a tree is one less than the total number of initial vertices and Steiner points.
2. Any two edges emerging from the same vertex form an angle of at least 120 °.
3. One, two or three edges can emerge from this vertex; if two edges come out, then the angle between them is greater than or equal to 120 °; if three, then they form angles of 120 ° with each other.
4. Three edges with angles of 120 ° emerge from each additional vertex (Figure 1).
Figure 1. Stages of operation of the Steiner algorithm

The Steiner algorithm based on the starting points builds a set of different trees that satisfy the above conditions. Some of these trees are called locally minimal trees. Not every locally minimal tree is the shortest possible solution of the problem. To transform the network into the shortest tree, called the globally minimal Steiner tree, global changes in the displacement of points can be used. As a result, there is a complete search of all possible locally minimal Steiner trees to find the shortest path (Figure 2). Since there is a constant change in the location of the Steiner points, the time to create all the minimal local trees and their search can be unlimited.

Figure 2. Relatively minimal Steiner trees

Further development of the Steiner algorithm was obtained by Melzak, who divided the set of all points into subsets and applied the Steiner algorithm in each subset.

The Steiner problem is NP-complete, so the algorithms of this problem cannot be used in CAD because of the long calculation time. As a result, heuristic algorithms were developed. One successful algorithm is the sequential introduction of additional vertices into the Prima-Kraskal tree [4].

We apply the Kruskal algorithm and Steiner algorithm for designing a biomethane gas pipeline between agricultural enterprises in the Belgorod region (Figure 3).

The total area of the territory of the Belgorod region is 27,100 km². There are 136 agricultural enterprises on the territory. We shall regard them as nodes of the graph.

We construct the minimal spanning tree using the Kruskal algorithm (Fig. 4). The length of the constructed network is 2,626.31 km.

We construct the Steiner tree on the basis of the Kruskal algorithm (Fig. 5). The length of Steiner's tree is 2,548.8 km, which is 77.5 km less or 2.95%.

In monetary terms, savings on working documentation during design is 37.66 million rubles and 413.51 million rubles at work [5].

Using the algorithm of the minimal covering spanning tree, a biometric gas network was built between the enterprises of the agro-industrial complex of the Belgorod region. Then the biometric network was refined using the Steiner algorithm. It can be concluded that the length of the gas network constructed according to the Steiner algorithm is 77.5 km shorter. Thus, the savings on construction of the network amounted to 451.17 million rubles.
Figure 3. Location of agricultural enterprises in the territory Belgorod region

Figure 4. Minimal spanning tree Kraskala

Figure 5. The Kraskal Tree and the Steiner Tree
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