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受限最小生成树算法在城镇管网布局优化中的应用研究

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摘要:随着天然气输配管网规模的大型化,管网系统进一步优化对提高运行的经济效益和利用率显得非常重要. 采用受限最小生成树算法对城镇燃气管网布局进行优化,并将该算法与最小生成树算法(prim)进行了比较. 仿真表明,该算法实用性强,对城镇天然气系统工程投资的评估预算有重要的参考价值.

关键词:燃气管网;拓扑优化;最小生成树;算法;管网结构设计

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随着天然气资源的开发,天然气已经成为大中城市的主要气源. 在燃气工程建设中,天然气管网的规划设计是一项重要内容. 油气集输工程是油气田地面工程的主体工程,其投资一般占整个油气田地面工程的 60% ～70%,约占整个油气工程的 40%[1-4]. 而在天然气输配系统优化中燃气管网布局优化又占有重要的位置. 目前燃气管网布局优化问题主要是指在给定气源和用户的地理位置后,确定燃气管网的最优拓扑结构[5]. 一般存在多种管道布置方案,从中选择最优的布局格式作为后续进行参数优化的基础. 国内外对于管径优化的研究较多,而布局优化问题则很少探讨[6],尤其是燃气管网规划设计往往凭经验确定管道的布置形式,这使管网的整体优化设计缺少了一个重要环节. 通常管网优化布置采用动态规划法、枚举法或图论中的 Dijkstra 法、避圈法等,对于较大规模的管网这些方法都存在一定的局限性[6].

本文采用受限最小生成树算法,对燃气管网布局进行优化,解决大规模计算量问题. 实现了管网的布局最优,给出了城镇燃气管网布局优化的方案,解决了管网建设的总投资最低的问题.

1 优化目标分析

1.1 拓扑优化的目标函数

管网拓扑优化的目标函数为

$$C = \mathrm{Min}\sum_{i=1}^{n}[(P_i + B_i)L_i]. \quad (1)$$

式中: C为管网建设总投资,元; i为管段序号; n为管网中管段的数量; P_i为管段 i的单位长度投资(也称为造价系数,与管径有关),元/m; B_i为管段 i的单位长度投资(与管径无关部分),元/m; L_i为管段 i的长度,m.

假定与管径无关的因素均已确定,即 B_i已确定,上述管网拓扑优化的目标函数可简化为

$$C = \mathrm{Min}\sum_{i=1}^{m}(P_iL_i). \quad (2)$$

1.2 布置优化策略

一般管材和管径的选择在不同程度上受到管网压力和燃气流量的制约,一是管道允许承受的压力与管材有关;二是在管材和流量均已确定的情况下,压力越大,管径越小. 以下给出下列管网布置的优化策略:

(1)将城市天然气管网分为高压、中压、低压三

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级.高压管网主要用作城市外围的输气干线,中压管网主要构筑市内骨干网并供工业用气,低压管网主要供居民用气;

(2)中压骨干网的构筑方式可采用环-树(即环与树的混合)型和树型两种拓扑结构.前者的优点是可靠性高,后者的优点是适于狭长型城市骨干网的构筑且造价较低;

(3)在符合有关规程规范的条件下,尽量在城市内多用中压管道,少用低压管道[7].

2 算法模型及仿真算例分析

2.1 算法模型

2.1.1 prim算法 Prim算法是采用贪婪策略进行设计的一种算法,它通常用来解决具有最大值或最小值的优化问题.从某一个初始状态出发,根据当前局部的而不是全局的最优决策,以满足约束方程为条件,以使得目标函数的值增加最快或最慢为准则,选择一个能够最快地达到要求的输入元素,以便尽快地构成问题的可行解.

(1)prim算法实现的步骤

Step1: E(T) = ϕ, S = {起始节点}, N = V - S.

Step2:如果N为空,算法结束;否则,转Step3.

Step3:寻找使 i∈S, j∈N,并且C(i, j)是最小的(i, j).

Step4: S = S∪{j}, N = N - {j}, T = T∪(i, j);转Step2.

其中:V是连通网G的节点集合;E(T)是最小生成树T的边集;S中存放已属于最小生成树T的节点集;N中存放剩余顶点的节点集;C(i, j)是从i到j的权值.(i, j)是i到j的边[8].

(2)prim算法的伪代码

```
Proc prim(G) {构造连通网G的最小生成树T};
E(T) = φ;
S = {起始节点};
N = V - S;
While (N < >NULL) or (E(T) < > n - 1) do
{
if i∈S and j∈N and C(i, j) = min_{j∈N}(C(i, j)) then
{
S = S∪{j}, N = N - {j}, T = T∪(i, j);
}
END P; {Prim}
```

2.1.2 受限最小生成树算法 受限最小生成树算法是对prim算法的改进.在prim算法的基础上,添加了一些限制条件,不仅考虑了当前局部的而且也考虑了全局的最优决策,使得它满足全局最优.

在本文城镇管网布局优化设计中,将这个限制条件设置为管网中节点的度数(即与节点相关联的边数),它不得超过某个常数 *B*. *B*的选择常与节点的流量和管段的流量有关,工程中*B*通常取3.

(1)受限最小生成树算法实现的步骤

Step1: V(T) = ϕ, E(T) = ϕ.

Step2:如果V(T) = V(G),算法结束;否则,转Step3.

Step3:寻找边(i, j) ∈E(G),并且C(i, j)是最小的(i, j).

Step4: E(G) = E(G) - (i, j),如果节点 j∉V(T)和节点j全属于V(T),转Step2.否则,转Step5.

Step5:如果节点 i∈V(T)并且节点 j∉V(T), E(T) = E(T) ∪(i, j), V(T) = V(T) ∪{i} ∪{j},如果D(i)大于B,转Step8,否则,转Step2.

Step6:如果节点 i∉V(T),并且节点 j∈V(T), E(T) = E(T) ∪(i, j), V(T) = V(T) ∪{i} ∪{j},如果D(j)大于B,转Step9,否则,转Step2.

Step7:如果节点 i∉V(T),并且节点 j∉V(T), E(T) = E(T) ∪(i, j), V(T) = V(T) ∪{i} ∪{j},转Step2.

Step8: E(T) = E(T) - (i, j), V(T) = V(T) - {j},转Step2.

Step9: E(T) = E(T) - (i, j), V(T) = V(T) - {j},转Step2.

其中:V(T)和E(T)分别为受限最小生成树T的节点集和边集.V(G)和E(G)分别为连通网G的节点集和边集.C(i, j)是从i到j的权值.(i, j)是i到j的边.D(i)是节点i的度数.D(j)是节点j的度数.B是预先确定的节点的度的最大值.E(T) = E(T) - (i, j)表示从边集E(T)中将边(i, j)删掉.V(T) = V(T) - {j}表示从节点集V(T)中将节点j删掉.

(2)受限最小生成树算法的伪代码

```
PROC minispantree(G); {构造连通网G的受限最小生成树T}
V(T) = φ, E(T) = φ;
While V(T) < >V(G) do
{ if (i, j) ∈E(G) and (i, j) = min{C(i, j) | (i, j) ∈E(G)} then
```

```
{
  E(G) = E(G) - (i, j);
  if (i∈V(T)) and (j∉V(T)) then
  {
    E(T) = E(T) ∪ (i, j), V(T) = V(T) ∪ {i} ∪ {j};
    if D(i) > B then
    {
      E(T) = E(T) - (i, j), V(T) = V(T) - {j};
    }
  }
  if (i∉V(T)) and (j∈V(T)) then
    {
    E(T) = E(T) ∪ (i, j), V(T) = V(T) ∪ {i} ∪ {j};
    if D(j) >B then
    {
      E(T) = E(T) - (i, j), V(T) = V(T) - {i};
    }
  }
  if (i∉V(T)) and (j∉V(T)) then
  {
  E(T) = E(T) ∪ (i, j), V(T) = V(T) ∪ {i} ∪ {j};
    }
  }
}
END P; {minispantree}[7]
```

2.2 仿真算例分析

管网布置如图 1所示,其中节点 18, 19, 20, 21是气源节点,分别利用上面提到的两种算法对该管网布置图进行拓扑优化.

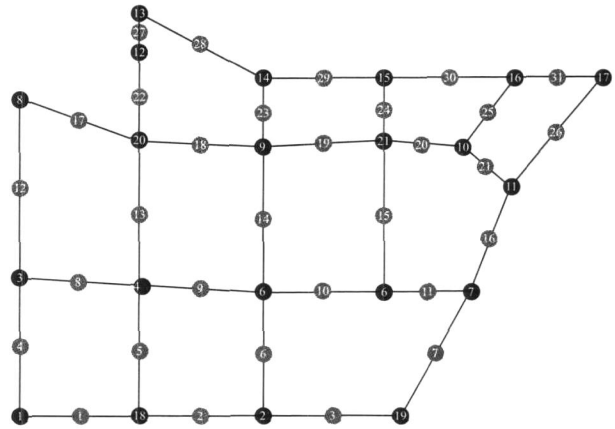

图 1 低压环状管网

Fig. 1 Low-pressure loop pipe network

其中:

(1)各个管段的管长见表 1所示;

(2)各个管段输出流量见表 2.

表 1 管段 1至 31的长度

Tab. 1 The length of pipe 1 - pipe 31

管段	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
长度/km	530	540	610	480	450	430	500	530	540	530	380	620	500	500	400	430
管段	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	
长度/km	550	500	530	350	310	310	340	340	420	600	130	570	530	580	380	

表 2 管段 1至 31的流量

Tab. 2 The flow rate of pipe 1 - pipe 31

管段	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
流量/($m^3 \cdot h^{-1}$)	543.24	549.35	513.80	235.24	690.29	437.15	719.41	52.46	260.60	49.07	73.53	241.29	651.77	428.32	724.40	68.87
管段	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	
流量/($m^3 \cdot h^{-1}$)	496.29	720.57	727.98	1074.59	363.94	379.12	165.23	993.19	150.64	7.82	229.12	75.12	140.65	436.54	170.18	

首先,利用 prim算法对图 1进行拓扑优化,最小生成树 T_1 如图 2所示.

利用 prim算法对图 1进行拓扑优化,所选择管段依次为: 5, 13, 22, 27, 18, 23, 14, 6, 1, 4, 19, 24, 20, 21, 25, 15, 11, 16, 7, 17.

然后,利用受限最小生成树算法对图 1进行拓扑优化,假设 $B=3$,最小生成树 T_2 如图 3所示.

利用受限最小生成树算法对图 1进行拓扑优化,所选择管段分别为: 27, 21, 22, 23, 24, 20, 11, 31, 15, 25, 6, 5, 4, 7, 13, 14, 1, 10, 2, 17.

2.3 两个算法的对比

根据图 2和图 3中各管段的流量、管径以及整个管网与管径有关的造价求出各个方案的总造价(其中,方案 1是利用 prim算法进行拓扑优化的结

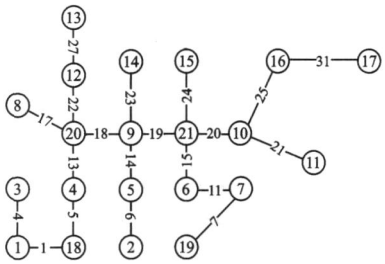

图 2 最小生成树 T_1

Fig 2 Minimum spanning tree T_1

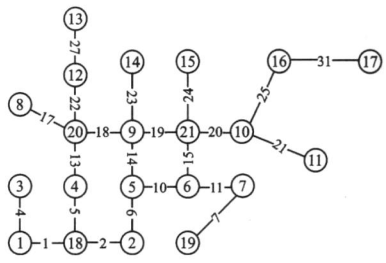

图 3 受限最小生成树 T_2

Fig 3 Limited minimum spanning tree T_2

果数据,而方案 2是利用受限最小生成树算法进行拓扑优化的结果数据)见表 3. 然后,将这 2个方案进行对比,选出优者.

通过对表 3中的方案 1和方案 2的总造价进行对比,可知方案 2优于方案 1.

表 3 规划方案

Tab. 7 Planning schemes

管段	管长/km	方案 1(总造价 36 965. 477元)				方案 2(总造价 34 039. 622元)			
		选中	管段流量/(m^3 · h^{-1})	管径标志	造价系数/(元 · km^{-1})	选中	管段流量/(m^3 · h^{-1})	管径标志	造价系数/(元 · km^{-1})
18-1	530	1	543. 24	245 * 7	4. 200 5	1	543. 24	245 * 7	4. 200 5
18-2	540					1	549. 35	245 * 7	4. 200 5
1-3	480	1	235. 24	219 * 6	3. 798 7	1	235. 24	219 * 6	3. 798 7
18-4	450	1	690. 29	245 * 7	4. 200 5	1	690. 29	245 * 7	4. 200 5
2-5	430	1	437. 15	245 * 7	4. 200 5	1	437. 15	245 * 7	4. 200 5
19-7	500	1	719. 41	245 * 7	4. 200 5	1	719. 41	245 * 7	4. 200 5
6-5	530					1	49. 07	245 * 7	4. 200 5
7-6	380	1	73. 53	245 * 7	4. 200 5	1	73. 53	245 * 7	4. 200 5
20-4	500	1	651. 77	245 * 7	4. 200 5	1	651. 77	245 * 7	4. 200 5
9-5	500	1	428. 32	245 * 7	4. 200 5	1	428. 32	245 * 7	4. 200 5
21-6	400	1	724. 40	245 * 7	4. 200 5	1	724. 40	245 * 7	4. 200 5
20-8	550	1	496. 29	245 * 7	4. 200 5	1	496. 29	245 * 7	4. 200 5
20-9	500	1	720. 57	273 * 7	5. 802 8				
21-9	530	1	727. 98	273 * 7	5. 802 8				
21-10	350	1	1 074. 59	273 * 7	5. 802 8	1	1 074. 59	273 * 7	5. 802 8
10-11	310	1	363. 94	245 * 7	4. 200 5	1	363. 94	245 * 7	4. 200 5
20-12	310	1	379. 12	194 * 6	3. 677 4	1	379. 12	194 * 6	3. 677 4
9-14	340	1	165. 23	159 * 5	3. 283 0	1	165. 23	159 * 5	3. 283 0
21-15	340	1	993. 19	299 * 8	6. 764 7	1	993. 19	299 * 8	6. 764 7
10-16	420	1	150. 64	219 * 6	3. 798 7	1	150. 64	219 * 6	3. 798 7
12-13	130	1	229. 12	159 * 5	3. 283 0	1	229. 12	159 * 5	3. 283 0
16-17	380	1	170. 18	219 * 6	3. 798 7	1	170. 18	219 * 6	3. 798 7

注:1. 标志为“1”表示选中,“0”表示未选中;2. 造价系数与管道外径成正比,只用于方案优化,不可用于方案投资估算.

3 总 结

本文对天然气输配管网的拓扑结构进行研究,针对管网拓扑结构的特点,研究了 prim 算法和受限最小生成树算法. prim 算法对燃气管网的拓扑结构进行优化时,只考虑管网的长度而不考虑节点的度,由于节点的度太大就会影响管段的流量,进而影响管径. 又由于造价系数与管径成正比,受限最小生成树算法既考虑管网的长度又考虑节点的度,进而弥补了 prim 算法本身的缺陷. 通过将 prim 算法和受限最小生成树算法分别用在仿真算例中,仿真算例验证了受限最小生成树算法的实用性和经济性,对城镇天然气系统工程投资的评估预算有一定的指导作用.

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pH value of original fracturing liquid is 7～8. Compared with SUN-1or ammonium persulfate separately, the gel-breaking time of the composite gel-breaker is decreased by 43%, the amount of the residue is decreased by 44.6%, the medium value of grain diameter is decreased by 40%, the damage to core is decreased by 60%, and the damaget to the conductivity of proppant is decreased by 43%.

Key words: bioenzyme; composite gel breaker; guar gum fracturing fluid; residue; core damage

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Design of the digital control system for small-power brushless DC motors

Abstract: A digital control system for small-power brushless DC motors is designed. The overall project design, the hardware principle and the control strategy of the control system are presented particularly. The design scheme in this paper is tested and the sample has been manufactured, which shows that the system has the characteristics of small size, simple structure, good portability, high reliability and stability, and it is suitable for the control of small-power brushless DC motors.

Key words: brushless DC motor; intelligent power module; control system; DSP

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Development of downhole fiber grating temperature-pressure sensor

Abstract: A sensor for the measurement of downhole temperature and pressure is designed. It uses the fiber bragg grating measuring principle. An especial package structure is designed for it. The sensor is of the pressure measuring range of 0～50 MPa and the pressure measuring accuracy of 0.1%, and the temperature measuring range of 0～150 ℃ and the pressure measuring accuracy of 0.5 ℃. It has also good stability and suits for downhole permanent monitoring. If it matches with separate layer testing tool, it can finish the separate-layer multi-point monitoring of temperature and pressure for rod pump and electric pump oil wells.

Key words: fiber bragg grating sensor; oil well; temperature; pressure; test

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Application of limited minimum spanning tree algorithm in the optimization of city natural gas pipeline network

Abstract: With the popularity of natural gas, the scale of natural gas transmission and distribution pipeline network is continuously enlarged. The natural gas pipeline network must be optimized in order to increase economic efficiency and pipeline network utilization. The limited minimum spanning tree algorithm is used in the optimization of urban natural gas pipeline network, and it is compared with the prim algorithm. The simulation results of a case show that the optimized result of the limited minimum spanning tree algorithm is more economic. The studied result in this paper can provide certain guidance for the assessment of urban natural gas engineering investment budget.

Key words: city natural gas network; topological optimization; limited minimum spanning tree algorithm; optimization of pipe network layout

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Study on multi-dimensional fuzzy analysis method based on data warehouse

Abstract: The traditional multi-dimensional analysis method is based on the definite dimension values. However, in the actual analysis process, the analysis demands of uncertain dimension values will be encountered due to the complexity and uncertainty of the environment. So a multi-dimensional fuzzy analysis method based on data warehouse is proposed by using the fuzzy membership function to make the dimension table value fuzziness and to convert the fact table on fuzziness dimension values. The conversion process and algorithm of the method are also presented. The multi-dimensional fuzzy analysis method based on data warehouse can effectively improve the flexibility and adaptability of multi-dimensional analysis.

Key words: data warehouse; multi-dimensional analysis; fuzzy set; fact table; dimensional table

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Design and implementation of the image monitoring system for automatic dialing alarm

Abstract: With the improvement of people's life, people pay great attention to security. The image monitoring system running on the operating system is μC/OS-II and the AT91SAM7x128 is selected as MCU chip which bases on ARM7. When the patrol signal is triggered, the image monitoring system can implement automatic dialing alarm through the public telephone network, and the image is in-