The Reliability Analysis of Metering System in Natural Gas Distribution Station based on Fuzzy Theory

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Abstract. As the core part of natural gas industry chain, the metering system plays an important role on security control. This paper use fault tree analysis method (FTA) to analyze failure cases and establish a system fault tree of metering system. Then using FCE to establish the evaluation index system on metering system. Finally, using AHP, FCE and characteristic quantity of safety grade to establish the approach to the reliability analysis of metering system of natural gas distributing station.

Keywords: Gas, Reliability, FCE, AHP.

1. Introduction

As the origin of city gas transmission and distribution system, the natural gas distributing station has become an important part of natural gas in the industrial chain. With the development of automation, the metering system of natural gas distribution station, which can make a real-time monitor on each process, is increasingly prominent [1]. If the metering system becomes invalid, the unsafe condition will be hidden and the energy accumulated gradually, which can lead to serious consequences. Therefore, it is necessary to analyze failure cases of metering system to find out main invalidation models and weak links, which is beneficial to the reliability of the metering system. This paper use FTA, FCE, AHP and Security feature vector to get a scientific model to evaluate the system reliability.

2. The evaluation model

2.1 The appraisal target system

By analyzing the failure cases of metering system of natural gas distributing station, it is found that the 15 basic events lead to failure of the metering system, the result is shown below in Figure 1.

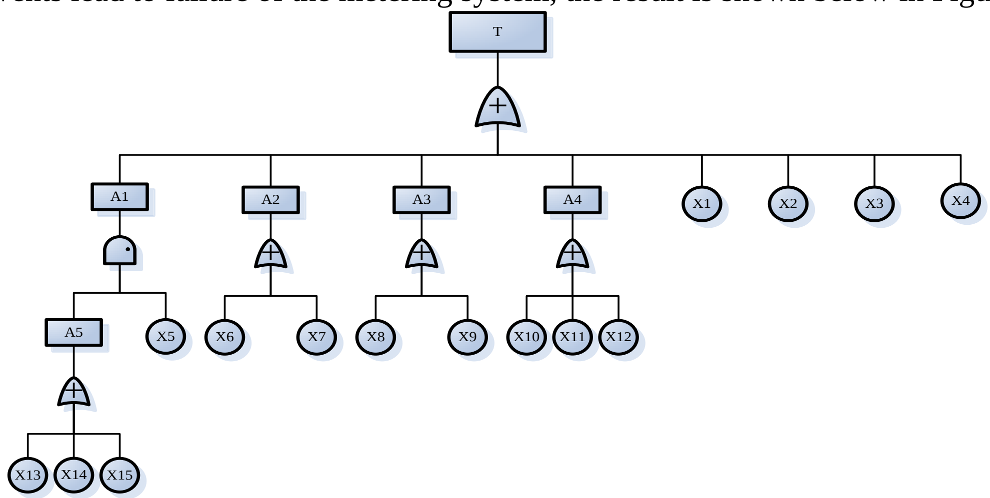

Fig.1 Invalidation factor of metering system

Table 1 Basic events

Symbol	Event	Symbol	Event
T	Invalidation	A_1	Internal corrosion
A_2	Non-standard installation	A_3	Non-standard working condition
A_4	Failure of transmitting device	A_5	Acid media
X_1	Creep	X_2	No maintenance
X_3	Over usage year limit	X_4	Non-standard usage
X_5	Hydrous media	X_6	Non-standard straight pipe
X_7	Off-design	X_8	Non-standard temperature condition
X_9	Wrong parameter setting	X_{10}	Disconnected cable
X_{11}	Burn-in	X_{12}	No-standard power supply
X_{13}	Chloride	X_{14}	Carbonate-hydroxide
X_{15}	Sulfide		

As shown in the Fig.1 and Table 1, the events lead to invalidation of metering system are divided into class A, class B class C and class D. The class A is T, the class B are A_1, A_2, A_3, A_4, x_1, x_2, x_3, x_4, the class C are A_5, x_5, x_6, x_7, x_8, x_9, x_{10}, x_{11}, x_{12}, the class D are x_{13}, x_{14}, x_{15}.

2.2 Fuzzy comprehensive evaluation model (FCEM)

The steps of FCE are shown as follows,

(a) Setting up the evaluation sets V= [v_1, v_2, v_3… v_n]. This paper use V= [A, B, C, D, E]. A means the metering system of natural gas distributing extremely reliable. E means the metering system very unreliable. From A to E, the reliability of metering system becomes increasingly worse.

(b) According to the appraisal target system, getting the weight of index of different factors in the same logical gate. D= [d_1, d_2… d_z], ($\sum_{i=1}^{z} d_i = 1$). The standard to obtain the weight of index is shown in Table 2[2].

Table 2 Basic events

Standard	Meaning
1	Both of them have the same importance
3	The former is slightly more important than the latter
5	The former is more important than the latter
7	The former is far more important than the latter
9	The former is extremely more important than the latter
2,4,6,8	Between the two standard
1,1/2,1/3…,1/9	If the ratio u_i to u_j *is* a_{ij}, then the ratio u_j to u_i is $1/a_{ij}$

Normally, the shape of determination matrix is shown below in equation 1[3],

$$A = \begin{bmatrix} a_{11} & \cdots & a_{1m} \\ \vdots & \ddots & \vdots \\ a_{n1} & \cdots & a_{nm} \end{bmatrix} \tag{1}$$

Obtaining the maximum eigenvalue λ_{max} and the maximum eigenvector of the matrix. In order to verify determination matrix is reasonable, it is necessary to use CR to check.

$$CR = \frac{CI}{RI} \tag{2}$$

$$CI = \frac{\lambda_{\max} - n}{n-1} \tag{3}$$

In the equations, *RI* is the average random consistency index, its value is shown in table 3[4].

Table 3 The value of *RI*

(*n*)	1	2	3	4	5	6	7	8	9
R•I	0.00	0.00	0.57	0.90	1.12	1.24	1.32	1.42	1.46

The determination matrix of the metering system is shown in table 4 and table 5.

Table 4 The value of determination matrix

U_k	u_1	u_2	u_3	u_4	u_5	u_6	u_7	u_8	u_9	u_{10}
u_1	1	4	4	2	3	3	6	4	-	-
u_2	1/4	1	1	1/3	1/2	1/2	3	1	-	-
u_3	1/4	1	1	1/3	1/2	1/2	3	1	-	-
u_4	1/2	3	3	1	2	2	4	3	-	-
u_5	1/3	2	2	1/2	1	1	4	2	-	-
u_6	1/3	2	2	1/2	1	1	4	2	-	-
u_7	1/6	1/3	1/3	1/4	1/4	1/4	1	1/3	-	-
u_8	1/4	1	1	1/3	1/2	1/2	3	1		-
u_9	-	-	-	-	-	-			1	1
u_{10}	-	-	-	-	-	-	-	-	1	1

Table 5 The value of determination matrix

U_k	u_{11}	u_{12}	u_{13}	u_{14}	u_{15}	u_{16}	u_{17}	u_{18}	u_{19}	u_{20}
u_{11}	1	1/2	-	-	-	-	-	-	-	-
u_{12}	2	1	-	-	-	-	-	-	-	-
u_{13}	-	-	1	1	-	-	-	-	-	-
u_{14}	-	-	1	1	-	-	-	-	-	-
u_{15}	-	-	-	-	1	3	3	-	-	-
u_{16}	-	-	-	-	1/3	1	1	-	-	-
u_{17}	-	-	-	-	1/3	1	1	-	-	-
u_{18}	-	-	-	-	-	-	-	1	1	3
u_{19}	-	-	-	-	-	-	-	1	1	3
u_{20}	-	-	-	-	-	-	-	1/3	1/3	1

u_1, u_2, u_3, u_4, u_5, u_6, u_7 and u_8 are the indexes in the same logical gate, their maximum eigenvalue λ_{max}=8.1359,

$$CI = \frac{\lambda_{\max}\text{-n}}{\text{n-1}} = 0.0194$$

$$CR = \frac{CI}{RI} = 0.0024 < 0.1$$

Through the consistency check, the evaluation factor weight vector is D_2=[0.3081,0.0711,0.0711,0.1990,0.1284,0.1284,0.0319,0.0711], the other evaluation factor weights are shown in table 6.

(c) Experts are invited to score and the fuzzy set of u_i (i=1, 2, 3, n) are obtained. R_i= [r_1, r_2, r, r_n), ($\sum_{i=1}^{n} r_i = 1$). The matrix consisting of index evaluation sets in the same logical gate is called evaluation matrix [5].

(d) Conducting multilevel fuzzy comprehensive evaluation from class D to class A.

$$B=D\times R= [b_1, b_2, b_3 \dots b_m] \quad (4)$$

$$Q= [q_1, q_2, q_3 \dots q_n] \quad (5)$$

$$P=B\times Q^T \quad (6)$$

B means fuzzy comprehensive evaluation matrix. Q means the weighing set, in this paper Q= [0.9, 0.7, 0.5, 0.3, and 0.1]. P means the reliability of metering system. We can determine the reliability of metering system according to the reliability of metering system P [6].

Table 6 the evaluation factor weights

Factors in the same logical gate	Evaluation index weight vectors
u_9,u_{10},	D_2=[0.5000,0.5000]
u_{11},u_{12}	D_{32}=[0.3334,0.6666]
u_{13},u_{14}	D_{31}=[0.5000 0.5000]
u_{15},u_{16},u_{17}	D_{34}=[0.6,0.2,0.2]
u_{18},u_{19},u_{20}	D_{41}=[0.4285,0.4285,0.1430]

2.3 Post-processing method

In order to make the result more reliable, it is necessary to get a further treatment of the results. In this paper, characteristic quantity of safety grade is used to achieve the goal. For fuzzy comprehensive evaluation matrix B, there is a value domain of safety grade= [0.5～1.5, 1.5～2.5, 2.5～3.5, 3.5～4.5, 4.5～5, 5]. The model of characteristic quantity of safety grade is shown in equation 7 to 10[7].

$$H_{UV}^{-} = \sum_{i=1}^{m} u_{vi}[w_i + \frac{u_{vi}(w_{i+1} - w_i)}{2}] \tag{7}$$

$$H_{UV}^{+} = \sum_{i=1}^{m} u_{vi}[w_{i+1} - \frac{u_{vi}(w_{i+1} - w_i)}{2}] \tag{8}$$

$$\pi_i = \frac{\int_{H_{UV}^{-}}^{w_{i+1}} u_{Fvi}(w)dw}{\int_{H_{UV}^{-}}^{w_{i+1}} u_{Fvi}(w)dw + \int_{w_{i+1}}^{H_{UV}^{+}} u_{Fvi}(w)dw} \tag{9}$$

$$\pi_{i+1} = \frac{\int_{w+1}^{H_{UV}^{+}} u_{Fvi}(w)dw}{\int_{H_{UV}^{-}}^{w_{i+1}} u_{Fvi}(w)dw + \int_{w_{i+1}}^{H_{UV}^{+}} u_{Fvi}(w)dw} \tag{10}$$

π_i Means the probability of grade I, π_{i+1} means the probability of grade i+1.

3. Application example

The model above-mentioned is used in an example. Through equation 4 to 6, it is obtained the reliability of metering system B= [0.6974, 0.1771, 0.1064, 0.0191, 0] and P=B×Q^T=0.81056. As 0.7＜0.81056＜0.9, the reliability of metering system is between grade A and grade B.

Through equation 7 to10,

The probability of grade A: $\pi_i = \frac{\int_{H_{UV}^{-}}^{w_{i+1}} u_{Fvi}(w)dw}{\int_{H_{UV}^{-}}^{w_{i+1}} u_{Fvi}(w)dw + \int_{w_{i+1}}^{H_{UV}^{+}} u_{Fvi}(w)dw}$ = 73.36%,

The probability of grade B: $\pi_{i+1} = \frac{\int_{w+1}^{H_{UV}^{+}} u_{Fvi}(w)dw}{\int_{H_{UV}^{-}}^{w_{i+1}} u_{Fvi}(w)dw + \int_{w_{i+1}}^{H_{UV}^{+}} u_{Fvi}(w)dw}$ =28.64%.

4. Conclusion

In this paper, the model to evaluate the reliability of metering system of natural gas distributing station has been established. The model consists of all the factors influencing the reliability evaluation. In the example, the analysis results show that the metering system of natural gas distributing station evaluated is very reliable. The result has been recognized by the engineer working at the natural gas distributing station. It is proved that the model established in this paper is appropriate to analyze reliability of the metering system of natural gas distributing station.

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