Supplementary Materials

S1. Monte Carlo simulation

When Monte Carlo method is used to determine the initial number of the standby compressors and estimate the reliability of the CS, the corresponding random number is firstly used to describe the compressor operating state, and then sampling is performed to obtain the system state, with which the pipeline working conditions can be obtained.

The sampling of the compressor unit status can be conducted as follows.

If there are *m* compressors in the system, and the operating status of each compressor is independent of each other. The outage probability of the *i–th* compressor is λ_i, of which represents its operating status. R is a random number that belongs to $[0,1]$. The probability function $P(x_i)$ of x_i is:

$$x_i = \begin{cases} 1 & 0 \le R \le \lambda_i \\ 0 & \lambda_i \le R \le 1 \end{cases} \quad \text{(S1)}$$

$$P(x_i) = \begin{cases} \lambda_i & 0 \le R \le \lambda_i \\ 1-\lambda_i & \lambda_i \le R \le 1 \end{cases} \quad \text{(S2)}$$

A sample of the system state is $X = (x_1, x_2, \cdots, x_m)$, of which the probability function should be:

$$P(X) = \prod_i P(x_i) \quad \text{(S3)}$$

Make $F(X)$ be the experimental function or flag function of the system. According to the statistics principle, the expectation $E(F)$ and variance $V(F)$ of the system state F can be obtained:

$$E(F) = \sum_{X_i \in \Omega} F(X_i) P(X_i) \quad \text{(S4)}$$

$$V(F) = \sum_{X_i \in \Omega} \left(F(X_i) - E(F) \right)^2 P(X_i) \quad \text{(S5)}$$

where Ω is the sample space. Actually, since the sample number is limited, the expected and variance could be estimated by:

$$\hat{E}(F) = \frac{1}{N} \sum_{i=1}^{N} F(X_i) \quad \text{(S6)}$$

$$\hat{V}(F) = \frac{1}{N} \sum_{i=1}^{N} \left(F(X_i) - \hat{E}(F) \right)^2 \quad \text{(S7)}$$

The error between the expected and theoretical values can be expressed as:

$$\hat{V}\left(\hat{E}(F)\right) = V(F)/N \quad \text{(S8)}$$

The accuracy of Monte Carlo simulation is based on the error of $\hat{E}(F)$ and $E(F)$, which can be measured by the coefficient of variance.

$$\eta = \sqrt{V\left(\hat{E}(F)\right)} \Big/ \hat{E}(F) \quad \text{(S9)}$$

Therefore

$$N = \frac{V(F)}{\left(\eta \hat{E}(F)\right)^2} \quad \text{(S10)}$$

In Eq. (S10), if we want to reduce the variance coefficient η and the number of samples N at the same time, we need to reduce the variance $V(F)$ of the samples. The main method to reduce the variance includes the state sampling and importance sampling.

The system reliability index can be expressed as:

$$E(F) = \sum_{x \in \Omega} F(x) P(x) \quad \text{(S11)}$$

where x is system status; $F(x)$ is reliability test function with x as independent variable; $P(x)$ is the probability distribution function of x; $E(F)$ is the expected value of the probability for the random function $F(x)$; Ω is the state space of the system.

(1) Importance sampling

Among the methods to reduce the variance, the importance sampling method is an effective method to reduce the variance and improve the sampling efficiency. With the expected value of the original sample unchanged, we can get:

$$E(F) = \sum_{X_i \in \Omega} P(X_i) F(X_i) = \sum_{X_i \in \Omega} \left[P(X_i) F(X_i) / P'(X) \right] P'(X) \qquad \text{(S12)}$$

Make $F'(X) = P(X_i) F(X_i) / P'(X)$, we can get:

$$E(F') = F' \bullet P' = \sum_{X_i \in \Omega} \left[P(X_i) F(X_i) / P'(X) \right] P'(X) = E(F) \qquad \text{(S13)}$$

Define the importance distribution function as:

$$P'(x_i) = \begin{cases} k\lambda_i & x_i = 1(outage) \\ 1 - k\lambda_i & x_i = 0(working) \end{cases} \qquad \text{(S14)}$$

where λ_i is the outage probability of the *i–th* component; k is optimal multiplier; x_i is the state of the *i–th* component.

Make $P'(X) = mP(X)$, $F'(X) = F(X)/m$, we can get:

$$m = \prod_i \left[x_i k + (1 - x_i) \frac{1 - k\lambda_i}{1 - \lambda_i} \right] \qquad \text{(S15)}$$

By examining the states of all components in the system one by one, m can be obtained, and then $F'(X)$ can be obtained.

An important step in the above calculation process is the selection of the optimal multiplier. At present, there are few studies on this value in the reliability analysis on CS. Fortunately, it has been calculated in power system.

$$k = -\left(B + \sqrt{B^2 - AC} \right) / A \qquad \text{(S16)}$$

$$\begin{cases} A = \beta_0 \bar{\lambda} - (1 - \beta_0) \bar{\lambda} (1 - \bar{\lambda}) \\ B = -\beta_0 \bar{\lambda} \\ C = \beta_0 \end{cases} \qquad \text{(S17)}$$

$$\begin{cases} \beta_0 = N_0 / (N_0 + N_1) \\ \bar{\lambda} = \sum_i (P_{Gi} \lambda_i) / \sum_i P_{Gi} \end{cases} \qquad \text{(S18)}$$

where β_0 is the ratio of the number of outage components to the total number of system components in the sample; P_{Gi} is the rated power; λ_i is the outage probability; $\bar{\lambda}$ is average value.

The flow chart of the optimal multiplier calculation is as follows:

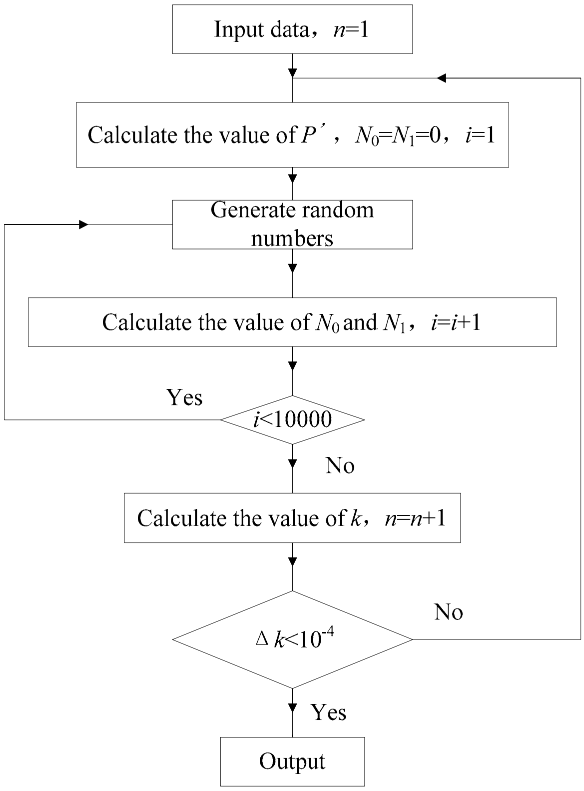

Figure S1. Flow diagram of the optimal multiplier.

After obtaining the optimal multiplier, importance sampling can be performed. The algorithm program is as follows:

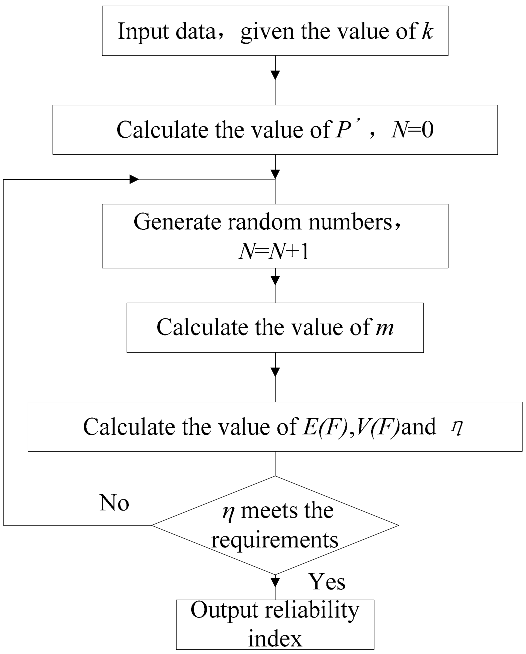

Figure S2. Principle diagram of importance sampling method.

(2) Improved importance sampling

To improve the efficiency or reduce the sample numbers, an improved importance sampling method is performed by the decentralized sampling method, which can be conducted as follows: firstly, divide the range [0,1] into intervals, in which the importance sampling is conducted separately. It should be noted that the same maximum eugenics k is used for each interval.

The sampling with equal dispersion sampling method can divide the interval [0,1] into h segments according to the maximum outage probability of components before sampling, h satisfies:

$$\frac{1}{h} \geq \max\{\lambda_1, \lambda_2, \cdots, \lambda_n\} \tag{S19}$$

The principle diagram of the improved importance sampling method can be seen in Figure S3.

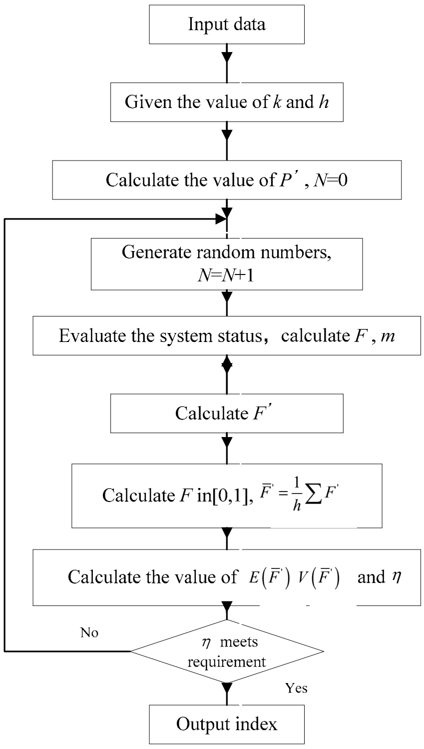

Figure S3. Principle diagram of modified importance sampling method.

S2. Results under normal conditions

The pressure and flow changes after the main line is stable can be seen in Figure S4.

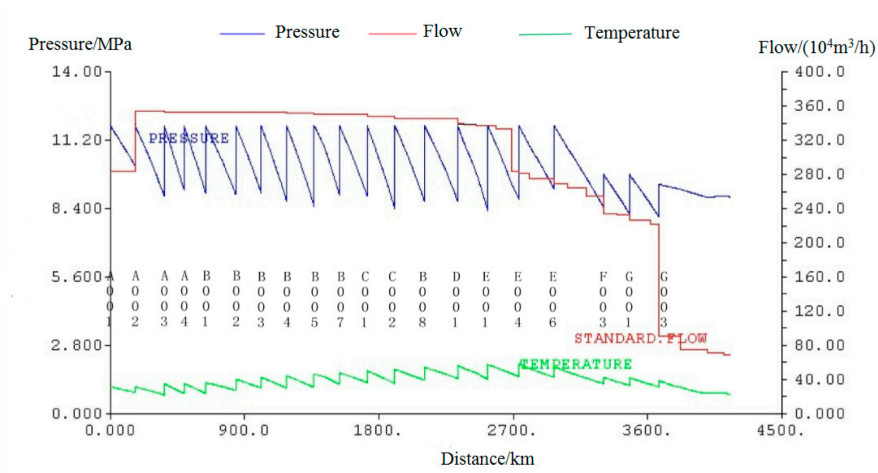

Figure S4. Main line graph under design condition.

The shaft power and inlet and outlet pressure of the compressor station can be seen in Table S1.

Table S1. Compressor shaft power.

Station No.	Single compressor shaft power/MW	Number of compressor under working	Inlet pressure/MPa	Outlet pressure/MPa
A001	11.4	2	9.05	11.85
A002	8.9	2	10.05	11.85
A003	10.3	3	8.75	11.85
A004	9.4	3	9.05	11.85
B001	9.9	3	8.95	11.85
B002	10.4	3	8.85	11.85
B003	10.3	3	8.95	11.85
B004	11.6	3	8.55	11.85
B005	12.8	3	8.35	11.85
B007	10.8	3	8.85	11.85
C001	11.1	3	8.75	11.85
C002	13.4	3	8.25	11.85
B008	12.2	3	8.55	11.85
D001	17.7	2	8.55	11.85
E001	13.8	3	8.15	11.85
E004	14.3	2	8.65	11.85
E006	11.6	2	9.05	11.85
F003	6.3	2	8.25	9.85
G001	7.1	2	8.05	9.85
G003	6.0	2	7.95	9.85