

Reliability Analysis of Submarine Mud-Lifting System Based on Bayesian Network

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Abstract: The seabed mud lifting system is the key equipment of offshore drilling, and the failure will cause serious economic loss. In order to improve its reliability, fault tolerant technology is adopted to design the electronic control system redundancy. The fault tree model of the system is established and a quantitative evaluation method based on the fault tree transformed into Bayesian network is proposed. Taking OREDA as the prior data of equipment failure, the failure probability of the system after 5 years operation is deduced by Bayesian network. According to the Bayesian network, the posterior probability of basic events is deduced backward, and the weak links of the system are analyzed. Considering the uncertainty of failure rate, the sensitivity of the system is analyzed. The results show that after five years of operation, the reliability of the newly designed redundant system with forward reasoning is 8.56% higher than that of the traditional system, and the most prone fault points of the electronic control system and mechanical system are the PLC controller and the submarine pump module. The sensitivity analysis verifies the correctness of the model.

1. Introduction

Sea mud jacking system is the key of the dual-gradient drilling technology, the main function is through the sea bottom in the installation of centrifugal pump and diaphragm pump will return to the sea sent to the ocean drilling platform, drilling fluid in drilling fluid return circuit in the form of two or two or more of the pressure gradient, adjust the lift pump speed control annulus pressure profile, so as to maintain the bottom hole pressure in the window [1]. However, with the increasing depth of offshore oil and gas development and the complexity of the deep-sea environment, the mud lifting system is faced with the influence of many factors. As a channel for drilling fluid to return to

the drilling platform, it has been working in the harsh environment of corrosion, high pressure and low temperature for a long time [2]. Therefore, it is necessary to analyze the reliability of mud lifting system.

At present, the main techniques of risk assessment for offshore operations include accident tree, fault tree analysis, Bayesian network and Markov chain. Because of its advantages of flexible structure and probabilistic uncertainty processing, Bayesian networks have been applied more and more frequently. Liu jian et al. [3] analyzed the leakage of underwater tree system based on Bayesian network, and found the weak point of the system by analyzing the event importance factor. Liu zengkai et al. [4] proposed a GO method to transform to Bayesian network, and studied the reliability and steady-state availability of the electronic control system of the submarine Bop. Wei ya rong et al. [5] analyzed the failure efficiency of shale gas transportation pipeline based on Bayesian network, and determined the risk factors affecting the pipeline failure. Xu jianqiang et al. [6] carried out dynamic risk assessment of building fire based on Bayesian network, and the effect of real-time monitoring could be achieved.

In this paper, the redundancy design of electronic control system in submarine mud lifting system is presented. Using the method of fault tree and Bayesian network, the Bayesian model of failure event of submarine mud lifting system is established, and the reliability of redundant system and traditional system is analyzed, which provides a new method for reliability analysis of offshore equipment.

2. Overview of theoretical methods

2.1 Bayesian network

Bayesian Network, also known as Belief Network (BN), is a directed acyclic graph composed of nodes and directed arcs of connecting nodes. If node A is connected to node B by A directed arc, then A is called the parent node of B, and B is the child node of A [4]. Each node is a set of random variables, and the probability relationship between each node is quantized by the probability of the random variable. The nodes in a Bayesian network are represented (Y_1, \dots, Y_N) by random variables, Assume that $P_a(Y_i)$ is the parent node Y_i of the node in the model, the conditional probability Y_i of the node can be expressed as $P_a(Y_i | P_a(Y_i))$, then the $P(Y_1, \dots, Y_N)$ joint probability distribution is:

$$P(Y_1, \dots, Y_N) = \prod_{Y_i \in \{Y_1, \dots, Y_N\}} P_a(Y_i | P_a(Y_i))$$

Because of the independence of Bayesian network node variables, the positive and negative bidirectional reasoning can be carried out on events, and the posterior probability of each variable can be obtained by reasoning [7]. Given the known variable B, the conditional probability of A given by the Bayesian network model is defined as:

Based on the static network, the dynamic Bayesian network integrates the network structure and time information to form a probability model with the function of processing time series data [8]. A dynamic Bayesian network is composed of a standard Bayesian network B_1 and a Bayesian network B_{\rightarrow} containing time slices. The standard Bayesian network's B_1 probability distribution at the initial time is $P(Y_t)$, and the conditional distribution of variables between two adjacent time slices is [9]:

$$P_a(Y_i | Y_t) = \prod_{i=1}^N P(Y_t^i | P_a(Y_t^i))$$

Where Y_t^i is the node $t(i=1,2,\dots,N)$ of time, $P_a(Y_t^i)$ is the parent node of Y_t^i . The dynamic Bayesian obeys the first-order Markov hypothesis, and the transfer probability of related nodes obeys the Markov Process. Suppose the current moment is t , the interval between the two time slices is Δt , and the failure probability of the element is expressed in terms of λ . The calculation formula of node transition probability with time-related in two time slices is [10]:

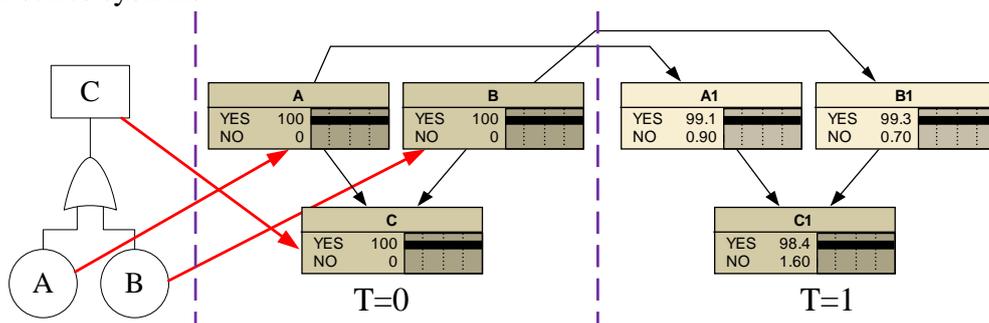
$$\begin{cases} P(Y_i(t+\Delta t) = Yes | Y_i(t) = Yes) = e^{-\lambda\Delta t} \\ P(Y_i(t+\Delta t) = No | Y_i(t) = Yes) = 1 - e^{-\lambda\Delta t} \end{cases}$$

2.2 Fault tree theory

Fault tree analysis (FAT) USES a variety of graphic elements to perform logical deduction according to the reverse order of events, and each event is independent of each other [3]. In fault tree analysis, it is assumed that the event only occurs and does not occur in two states, namely, normal or fault, and the error of fault tree calculation results is large due to many interference factors, large calculation amount and complex calculation.

2.3 The transformation of fault tree analysis into Bayesian network

In the process of transforming fault tree analysis into Bayesian network, the logic gate relation of fault tree should be transformed into the corresponding Bayesian network node variable. The transformation between the fault tree and the Bayesian network corresponds to each other. Each basic event of the fault tree is converted into the corresponding parent node of the Bayesian network. Each top event of the fault tree is converted into the corresponding child node of the Bayesian network [11]. Bayesian networks were subsequently extended to dynamic Bayesian networks [8]. Fig.1 shows the Bayesian network expression of the series-parallel relationship in the fault tree, and event $C=1$ is defined as failure. It can be seen from the figure that the structure and data of series and parallel systems are the same at the same time, but the reliability of parallel systems is higher than that of series systems.



$$P(C = 1 | A = 0, B = 0) = 0$$

$$P(C = 1 | A = 0, B = 1) = 1$$

$$P(C = 1 | A = 1, B = 0) = 1$$

$$P(C = 1 | A = 1, B = 1) = 1$$

(a) Series

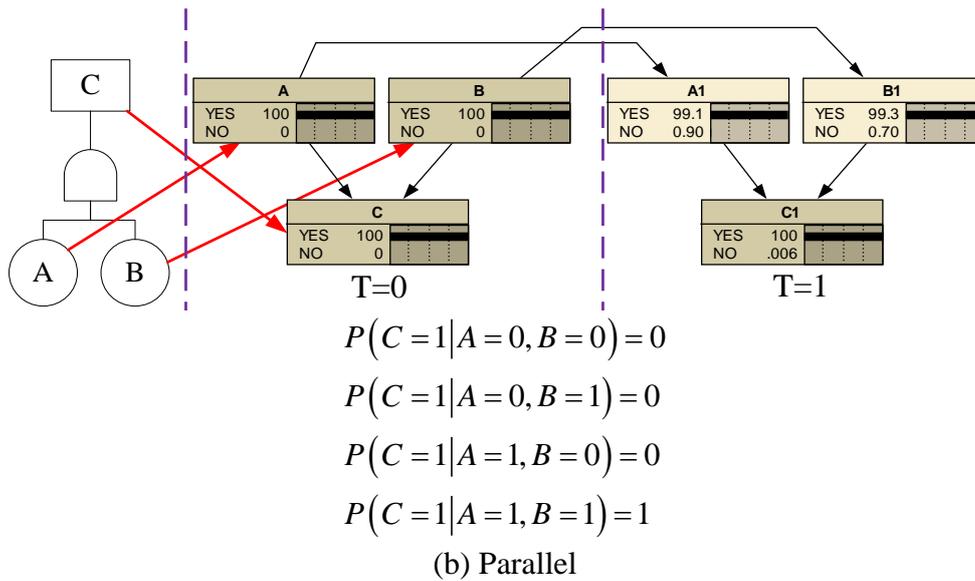


Figure. 1 Shows a simple series parallel mapping

3. The example analysis

3.1 How the mud lifting system works

The submarine mud lifting system is mainly composed of electric control system, pressure sensor, flow sensor, mud lifting pump, motor, rotary electric valve and mud return pipeline. During the drilling process, the drilling fluid containing cuttings enters the mud return pipeline through the suction module and is supercharged to the drilling platform by the mud lifting pump. Pressure sensors and flow sensors are installed on the mud pipeline to measure the pressure and flow of the mud return pipeline, and then the motor speed is controlled by an electronic control system. In the conveying process, all the equipment is working under corrosion, low temperature and high pressure, which is prone to failure [1-2]. The system composition is shown in Fig.2.

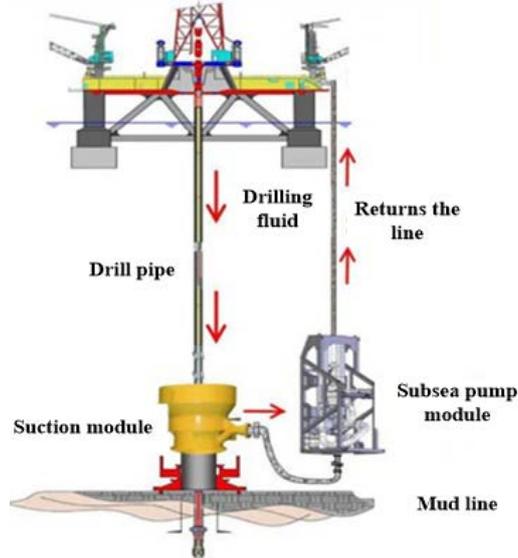


Figure. 2 Mud-lifting system composition

Failure of components in traditional electronic control system will seriously affect the work efficiency. In view of the traditional electric control system reliability is low, the author adopts the technology of the fault tolerance design the electric control system of a new set of redundancy, small fault generally will not affect the normal operation of the system, monitoring and control system is shown in Fig.3, electric control system hardware configuration consists of the control unit, input module, output module, switches, etc. The central control unit is to control the speed of the mud pump and monitor the pressure and flow of the submarine pipeline. It is composed of PLC, two control panels and a workstation. It is the core part of the mud lifting system.

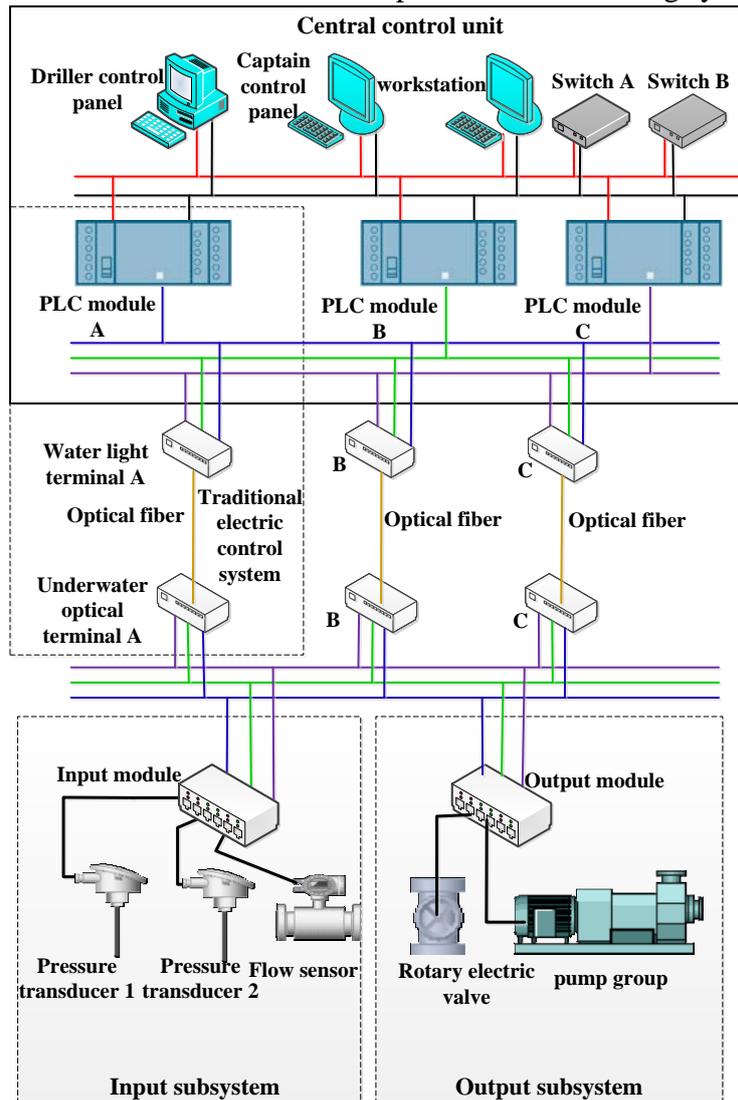


Figure. 3 Composition diagram of monitoring and control system

3.2 Establish fault tree

Built according to the theory of fault tree analysis, select the mud jacking system failure as the top event, because the mud jacking system considering the redundancy design, focusing on mud jacking system possible leaks, sensor failure, the failure of electric control system and pumps, other secondary module assume completely reliable and the analysis of mud jacking system structure, the system's fault tree, as shown in Fig.4. The failure probability data table is summarized by

investigating and collecting the failure basic events of the main components of the seabed mud lifting system and referring to the offshore platform reliability data manual [4,12], as shown in Tab.1.Set up the fault tree.

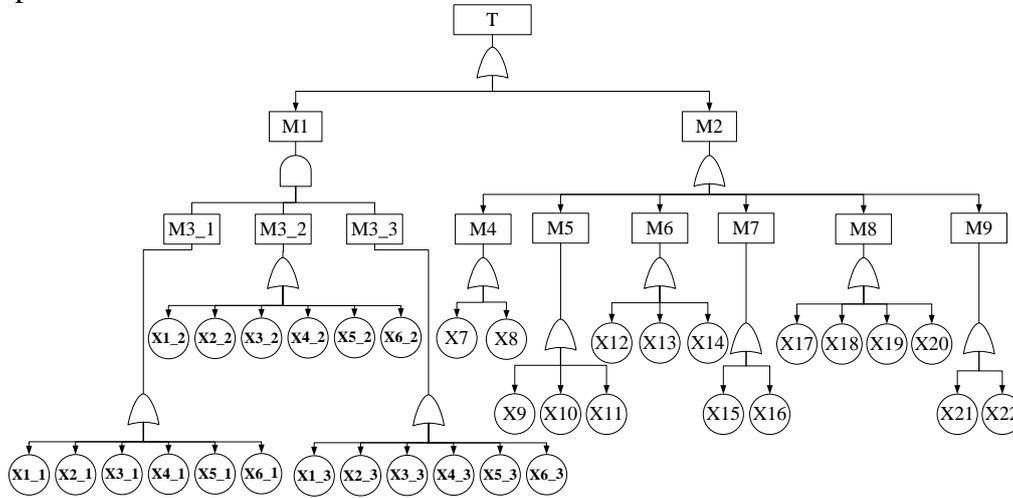


Figure. 4 Failure tree of submarine mud-lifting system

Table 1 Failure probability table of basic events

Parts	Describe	Independent failure rate	Parts	Describe	Independent failure rate
T	Mud lifting system failed	—	X6	Control box	1.1433E-6
M1	Monitoring control system failure	—	X7	The probe wear	3.25E-6
M2	Failure of mechanical system	—	X8	Display instrument anomaly	0.85E-6
M3_1	Monitor control channel 1	—	X9	Low output high reading	0.28E-6
M3_2	Monitor control channel 2	—	X10	High output low reading	0.98E-6
M3_3	Monitor control channel 3	—	X11	Flow sensor wear	2.36E-6
M4	Pressure sensor failure	—	X12	Pipeline interface leakage	0.96E-6
M5	Flow sensor failure	—	X13	Structural wear failure	1.56E-6
M6	Rotating electric valve fails	—	X14	Valve leaks when closed	0.3E-6
M7	Pump failure	—	X15	Axis wear	1.87E-6
M8	Motor fault	—	X16	The impeller wear	2.61E-6
M9	Pipeline failures	—	X17	Pump body internal leakage	0.87E-6
X1	Control panel failure	3.153E-6	X18	External leakage of pump body	2.25E-6
X2	Optical terminal machine failure	7.3982E-6	X19	Fever abnormal	0.21E-6
X3	PLC processor failure	1.82E-5	X20	Output instability	0.36E-6
X4	Input module	9.798E-6	X21	Joint leakage	0.25E-6
X5	Output module	9.790E-6	X22	The tube body crack	0.17E-6

3.3 Construct Bayesian network

In this paper, Bayesian software is used to obtain the Bayesian network model of system failure according to the transformation rules from fault tree to Bayesian network, as shown in Fig.5. By means of the electronic control system channel 1(M3_1), nodes X1_1, X2_1, X3_1, X4_1, X5_1, X6_1 at time T=0 represent the independent failure probability of the control panel, optical terminal, PLC processor, input module, output module and control box, and all nodes have only two states of normal or failure. In the process of dynamic Bayesian reasoning, the time interval is set to January, the initial time is T = 0, and each module is completely reliable. According to table 1 and transformation formula (4), parameters of each time period of dynamic Bayesian were learned.

3.4 System reliability assessment

According to Bayesian forward reasoning, the reliability of the mud lifting system is obtained, as shown in Fig.6. As the running time increases, the reliability of the system decreases. When the system was running for 5 years, the reliability of the newly designed redundant system and the traditional system were 13.71% and 5.15% respectively, and the reliability of the redundant electronic control system and the traditional electronic control system were 31.37% and 11.79% respectively. The parts of the mechanical system are analyzed, as shown in Fig.7. With the increase of operating time, the reliability of mud pump and sensor is the lowest.

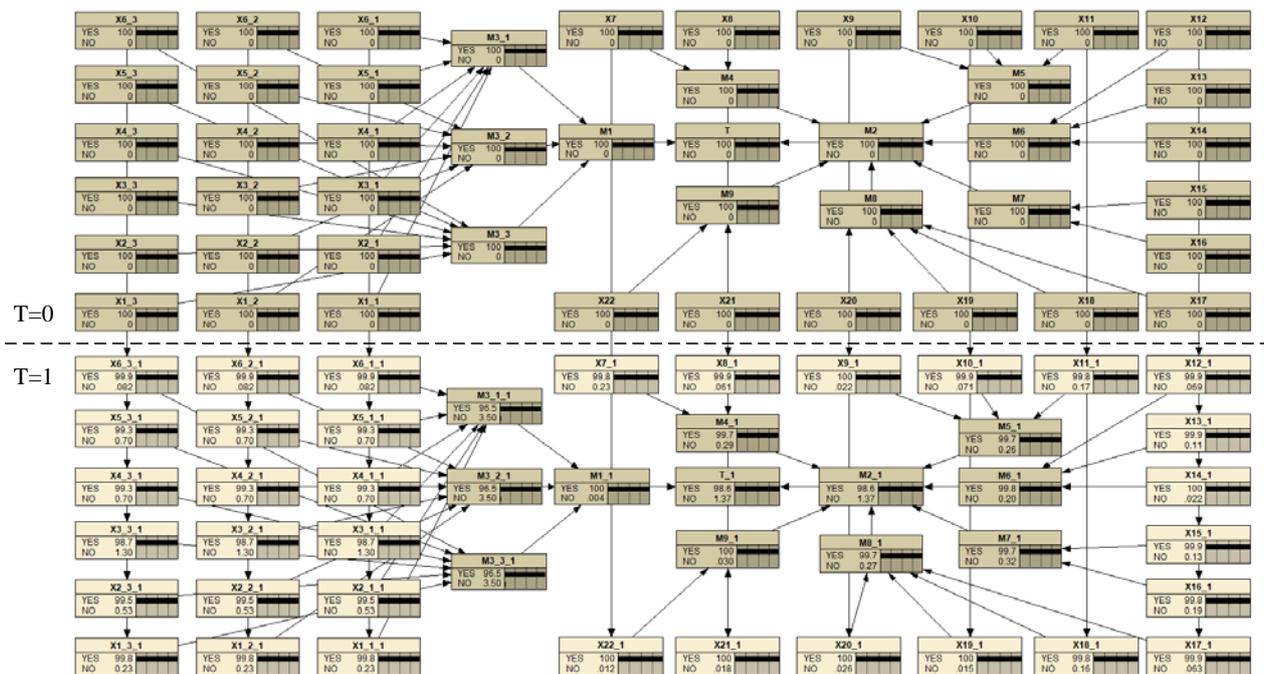


Figure. 5 Bayesian network for failure of mud-lifting system

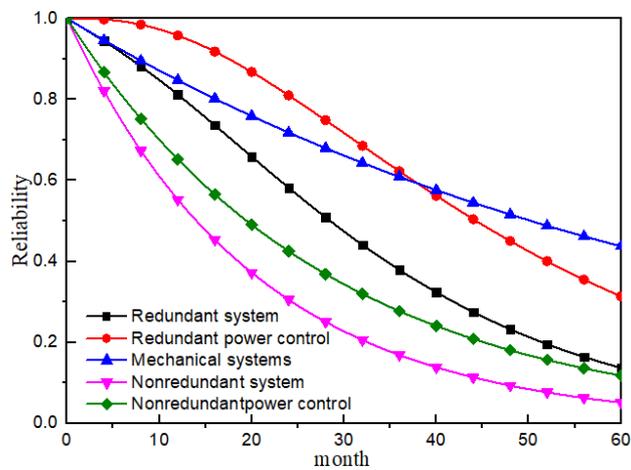


Figure. 6 Reliability of mud-lifting system

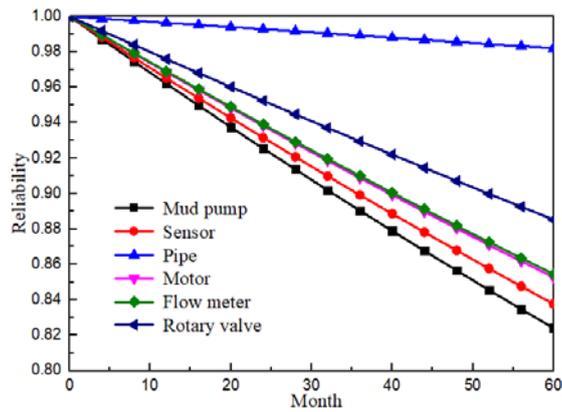


Figure. 7 Reliability of mechanical system components

According to Bayesian backward reasoning, the prior probability represents the probability of the occurrence of basic events, the posterior probability represents the probability of the occurrence of basic events in the case of special accidents, and the posterior probability can be used to determine the importance of basic events affecting the occurrence of top events [13]. The failure probability T of the mud lifting system was set as 1 to obtain the posterior probability of system components and analyze the weak links of the System. After the cumulative operation of the system for 5 years, the difference between the posterior probability and the prior probability of the mud lifting system equipment is compared, as shown in FIG. 8. The analysis results show that the node X3, X4 and X5 have the highest posterior probability, and the PLC processor module and the input and output module are the weak links of the system, so they should be inspected at high frequency. Node X22 has the least posterior probability, and the pipeline system has the least impact on the mud lifting system within 5 years. Other parts can reasonably arrange the maintenance frequency according to the difference between the posterior probability and the prior probability [14].

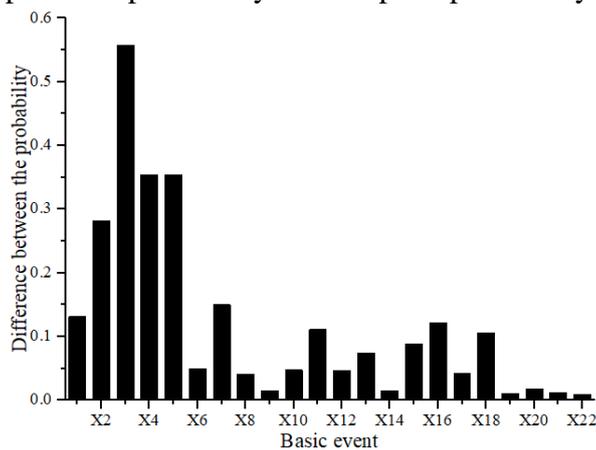


Figure. 8 Basic event significance

3.5 System sensitivity analysis

Sensitivity analysis assumes that the failure rate is uncertain, and studies the effect of the change of results by changing the failure rate [4]. The reliability of the two systems in operation for 5 months is calculated. It is assumed that the uncertain value range of system failure efficiency is. The

impact of failure efficiency on the reliability of redundant systems and non-redundant systems is shown in Fig.9. It can be seen that the lower the failure rate, the higher the reliability of the system. The failure rate of redundant electronic control has the least impact on the reliability of the system, because the redundant electronic control system is a parallel system composed of three lines. Non-redundant electronic control has a great impact on the system, because the non-redundant system is composed of a series of lines.

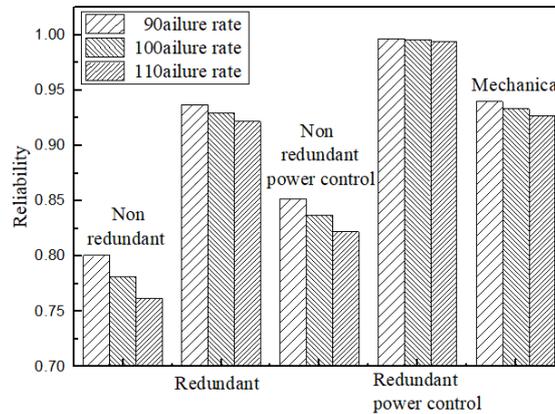


Figure. 9 System sensitivity

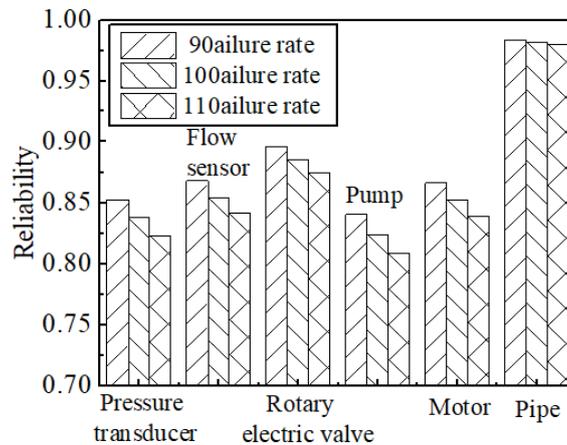


Figure. 10 Sensitivity of mechanical systems

The effect of failure rate on the mechanical part of the mud lifting system is shown in Fig.10. The influence degree of failure rate of mechanical components on the reliability of mud lifting system is listed in order from the largest to the smallest: > pressure sensor > motor > flow sensor > rotary electric valve > pipeline.

4. Summary

1) For the electronic control system, fault tolerant technology is adopted, and redundant electronic control system is designed. Minor faults will not affect the normal operation of the system, so as to meet the requirements of high reliability of offshore equipment.

2) The reliability analysis of seabed mud lifting system using dynamic Bayesian network

provides a new method for reliability analysis of offshore equipment.

3) The fault tree model of mud lifting system is established, and the method of transforming fault tree into Bayesian network is used [15]. After 5 years of operation, the reliability of redundant system and non-redundant system is 13.71% and 5.15% respectively.

4) According to the reverse reasoning of Bayesian network, it is concluded that PLC processor and input and output module are the most vulnerable links in the system, which are the weak links of the system. It can provide reference for equipment maintenance personnel to find fault points and save maintenance time.

5) Analyzed the impact of uncertainty of failure efficiency on the reliability of the system. The smaller the failure efficiency, the higher the reliability of the system. The failure rate of mechanical components has a sort of influence on the reliability of the system, which can guide the maintenance personnel to arrange the maintenance frequency reasonably.

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