Seminar in NTNU

Our recent research…

Dr. Baoping CAI

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Personal profile

Dr. Baoping CAI

- Associate professor in China University of Petroleum
- "Hong Kong Scholar" researcher in City University of Hong Kong

Research interests:

- Reliability engineering
- Fault diagnosis
- Risk analysis
- Bayesian networks methodology
- Bayesian networks application
- Resilience

Contents

- 1. Subsea systems
- 2. Reliability methodology
- 3. Fault diagnosis methodology

1. Subsea systems

1.1. Subsea BOP system

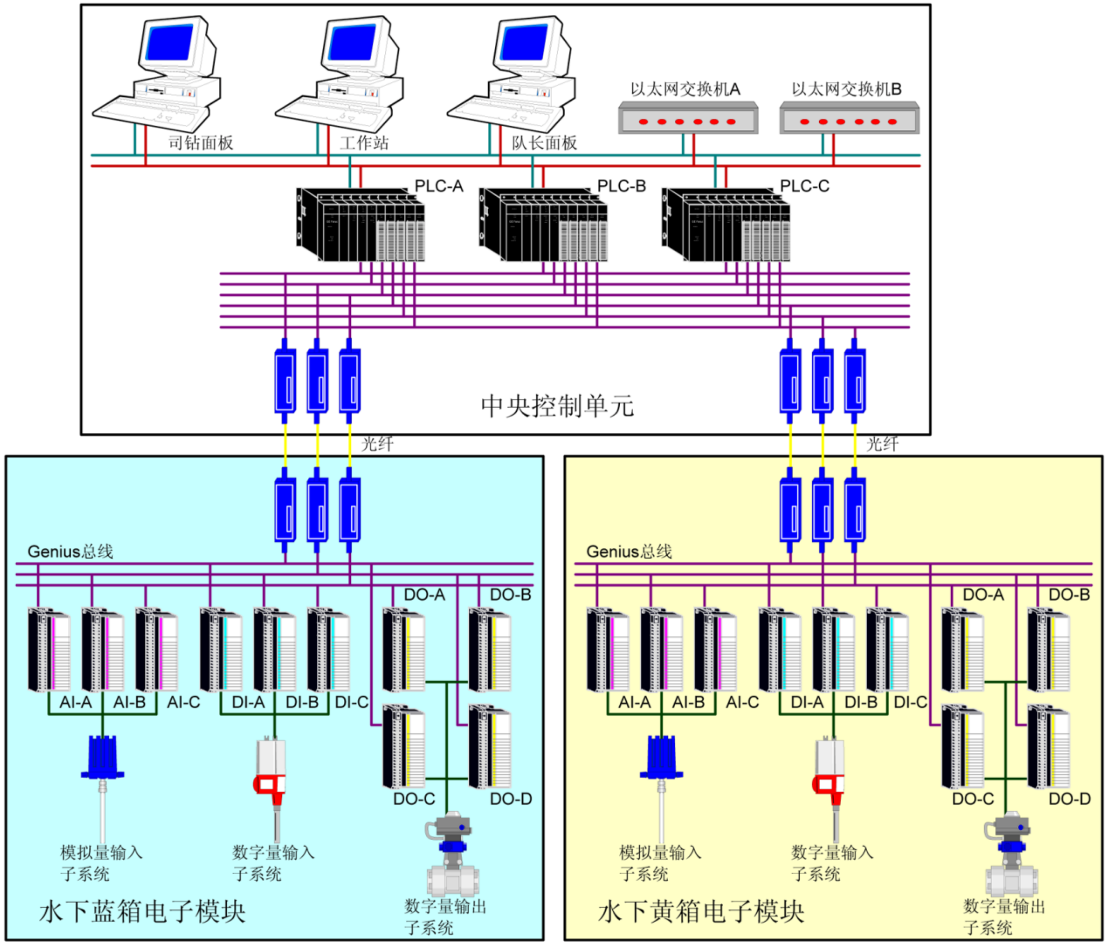
Cameron

Hydril

NOV

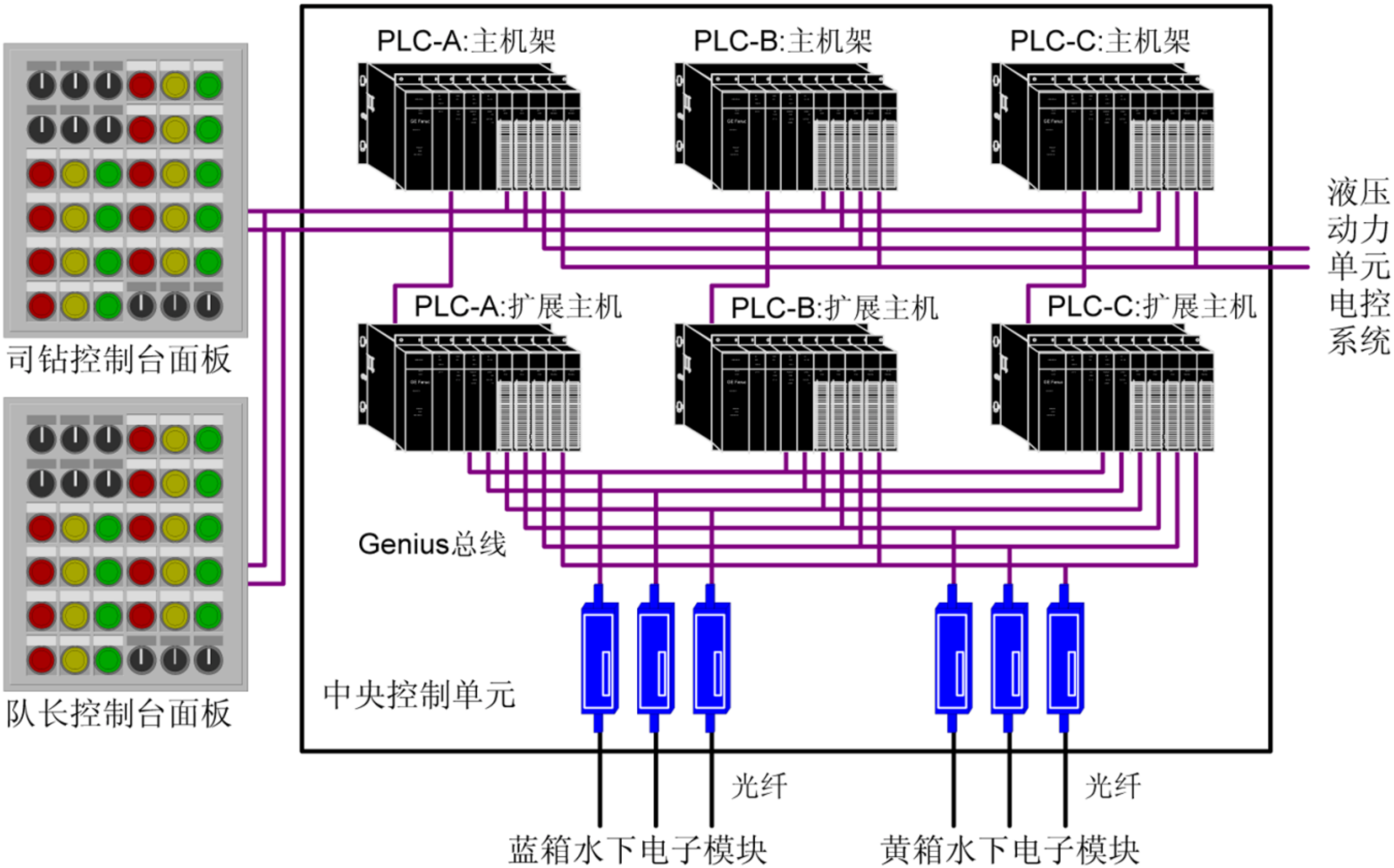
Deepwater subsea BOP systems

1. Subsea systems



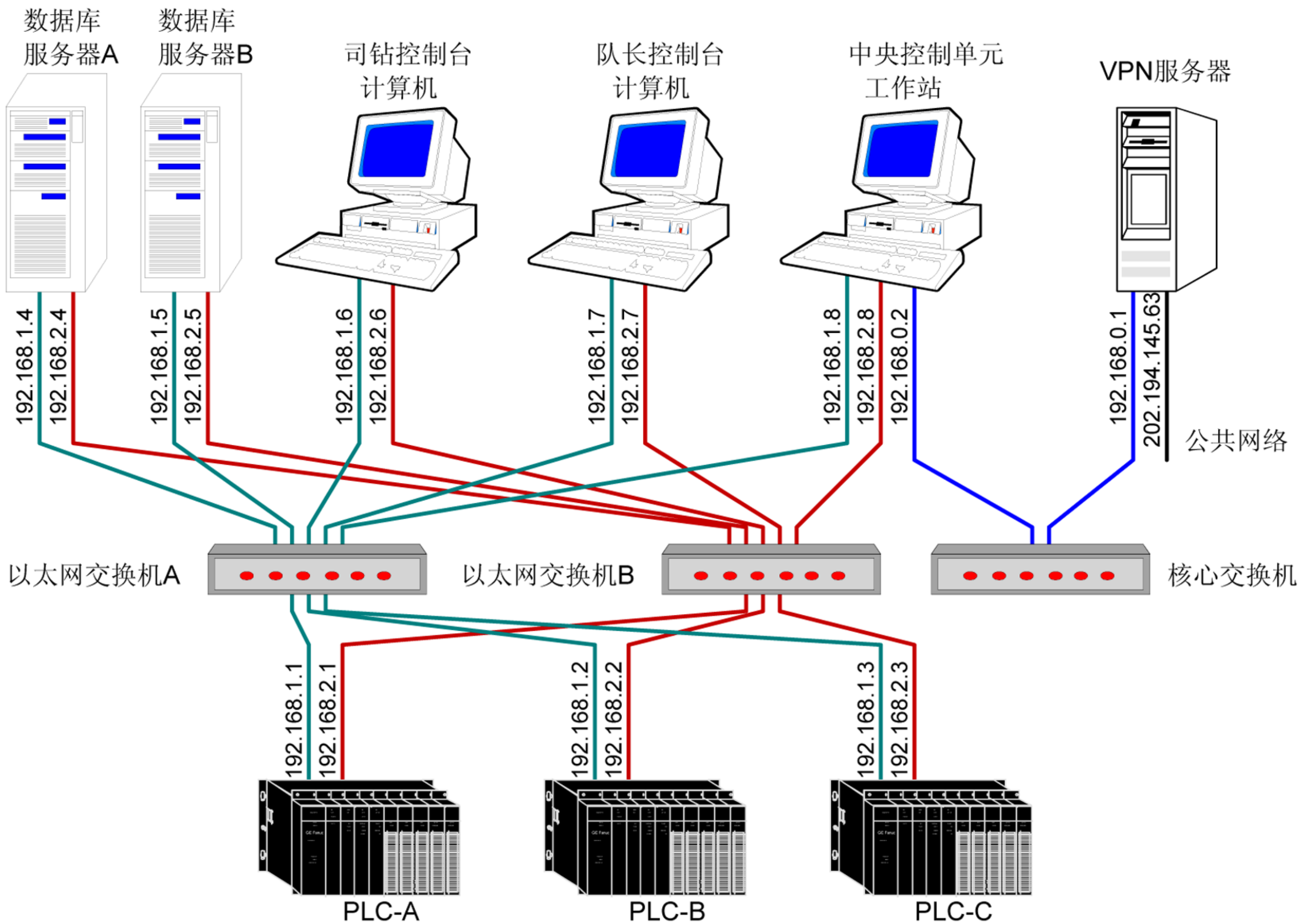
3000 m subsea BOP control system developed by China University of Petroleum (Cai, ISA, 2012)

1. Subsea systems



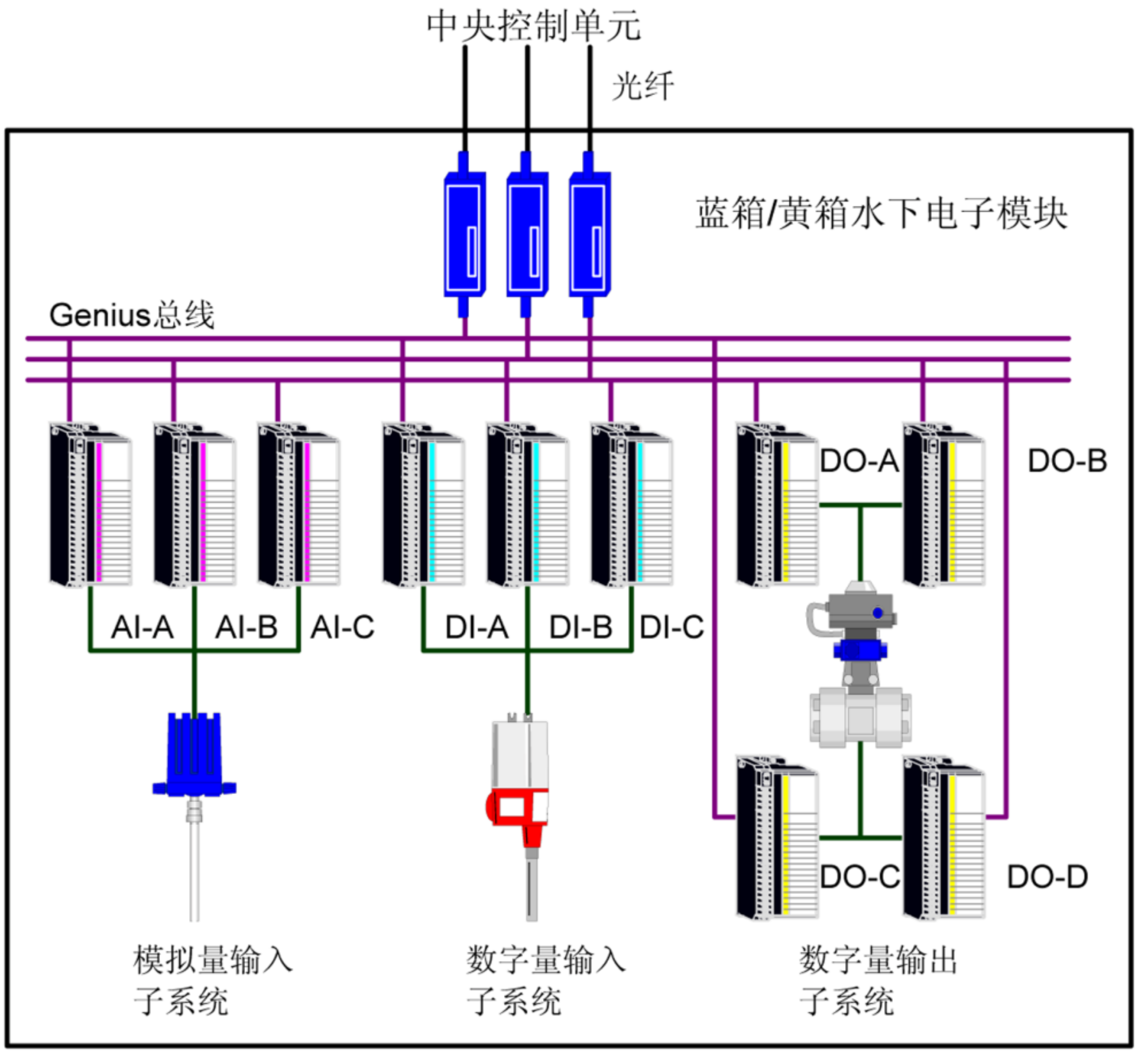
System configuration of triple redundant controller

1. Subsea systems



Architecture of dual redundant Ethernet.

1. Subsea systems

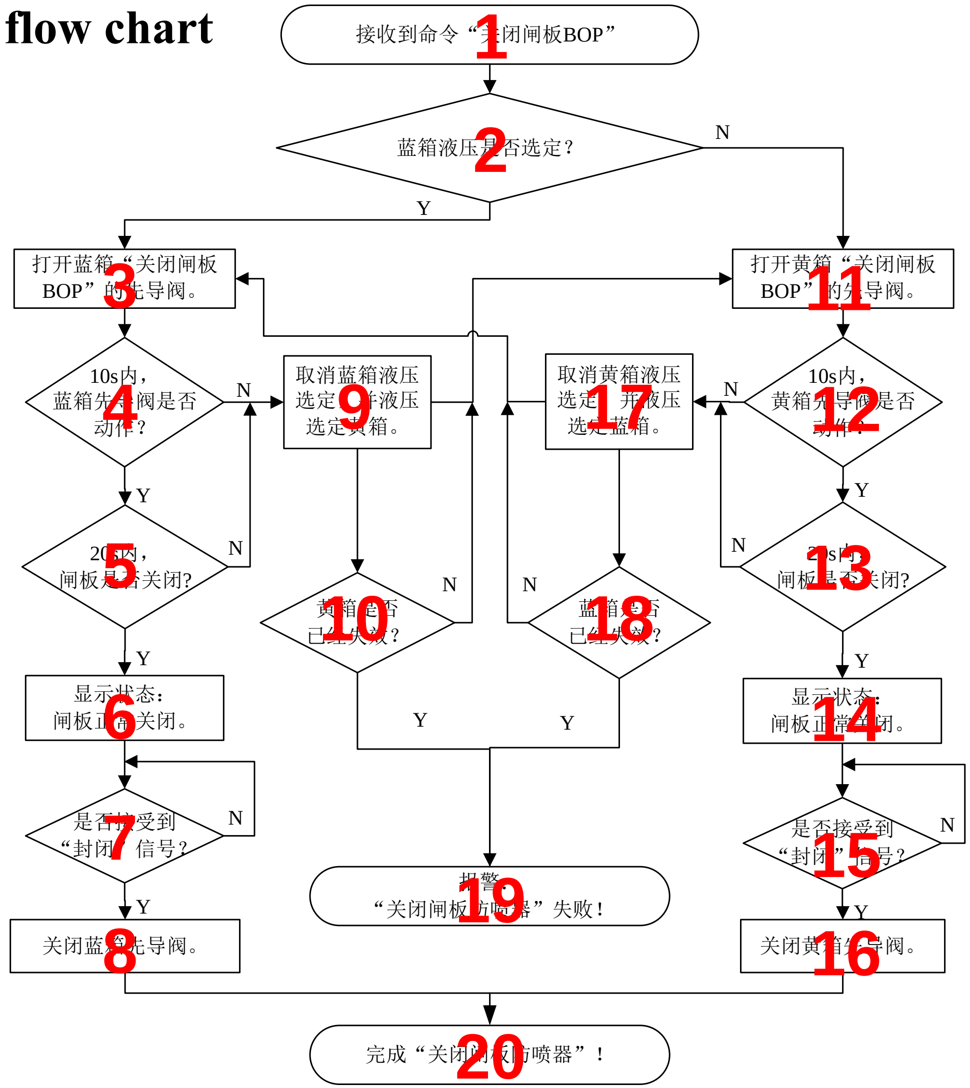


Subsea electronic module (SEM)

1. Subsea systems

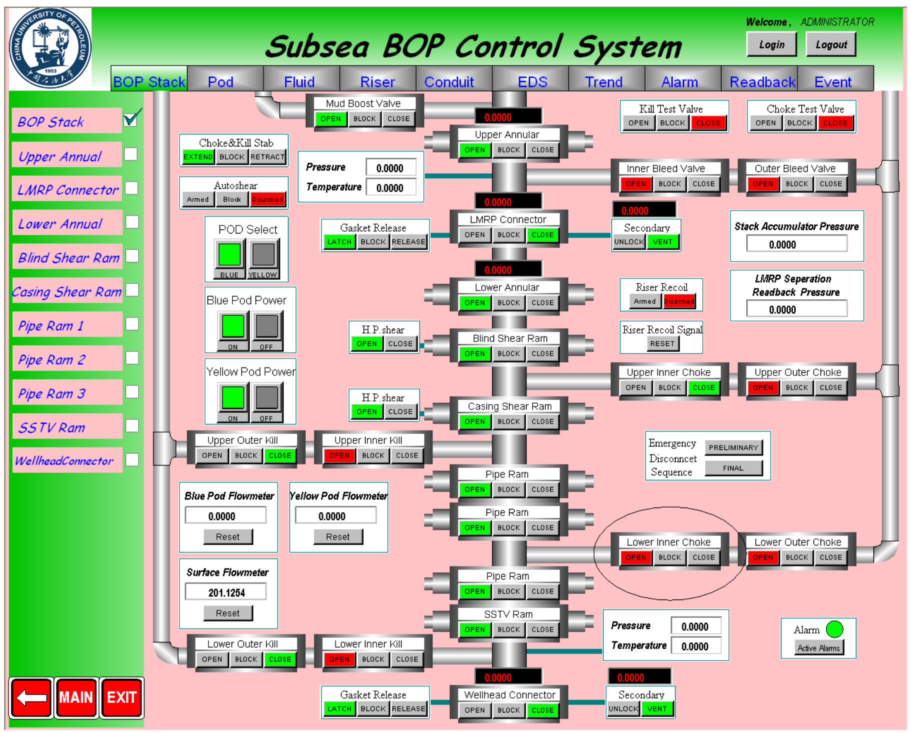
"Turn off ram BOP" control logical flow chart

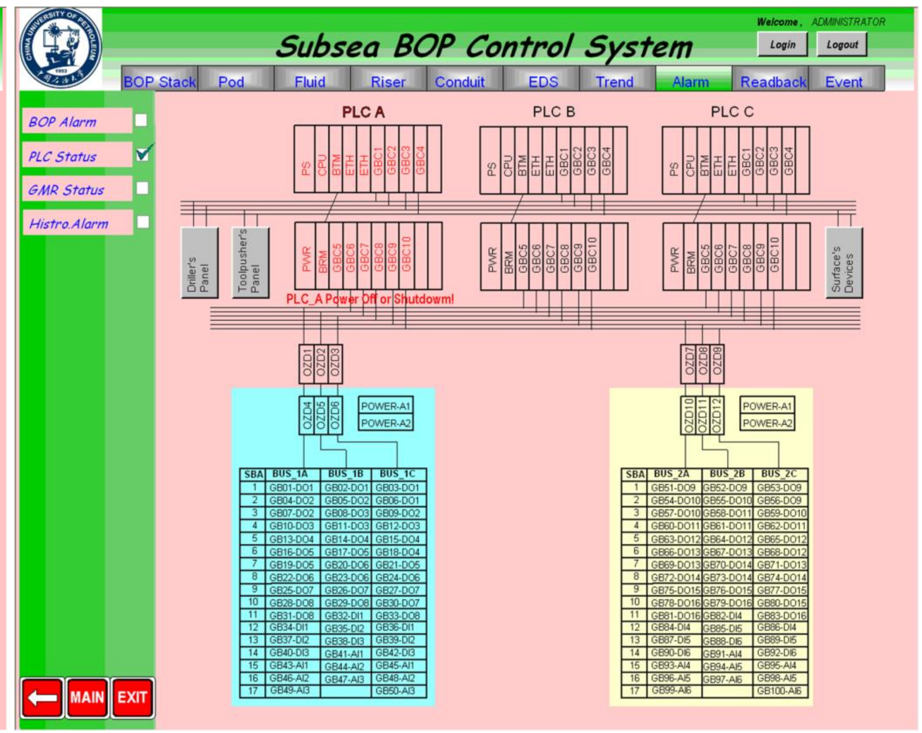
- ✓ 1. Receive the order "turn off flashboard BOP".
- ✓ 2. Is the hydraulic pressure chosen?
- ✓ 3. Turn on the pilot valve "turn off flashboard BOP" in blue box.
- ✓ 4. Whether the pilot valve in blue box take action in 10 seconds.
- ✓ 5. Whether the flashboard turn off in 20 seconds.
- ✓ 6. Display status: the flashboard turns off normally.
- ✓ 7. Whether receive the "turn off" signal.
- ✓ 8. Turn off pilot valve in blue box.
- ✓ 9. Cancel blue box hydraulic pressure and choose yellow box.
- ✓ 10. Whether the yellow box loses efficacy.
- ✓ 11. Turn on the pilot valve "turn off flashboard BOP" in yellow box.
- ✓ 12. Whether the pilot valve in yellow box take action in 10 seconds.
- ✓ 13. Whether the flashboard turn off in 20 seconds.
- ✓ 14. Display status: the flashboard turns off normally.
- ✓ 15. Whether receive the "turn off" signal.
- ✓ 16. Turn off pilot valve in yellow box.
- ✓ 17. Cancel yellow box hydraulic pressure and choose blue box.
- ✓ 18. Whether the blue box loses efficacy.
- ✓ 19. Alarm: "turn off flashboard BOP" fails!
- ✓ 20. Complete "turn off flashboard BOP"!



Electronic control system software development

1. Subsea systems

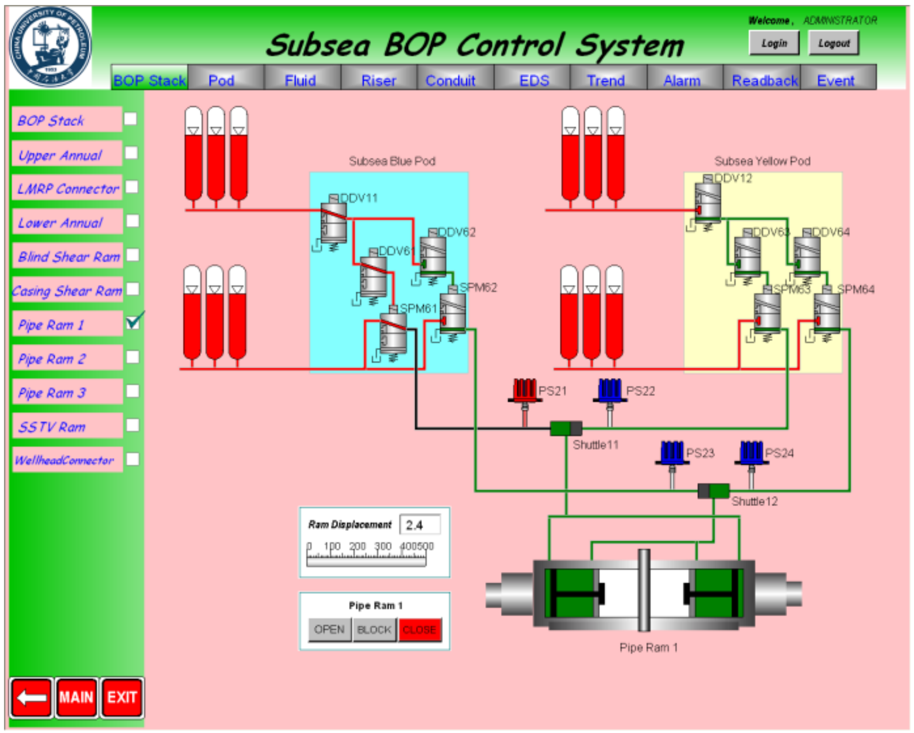




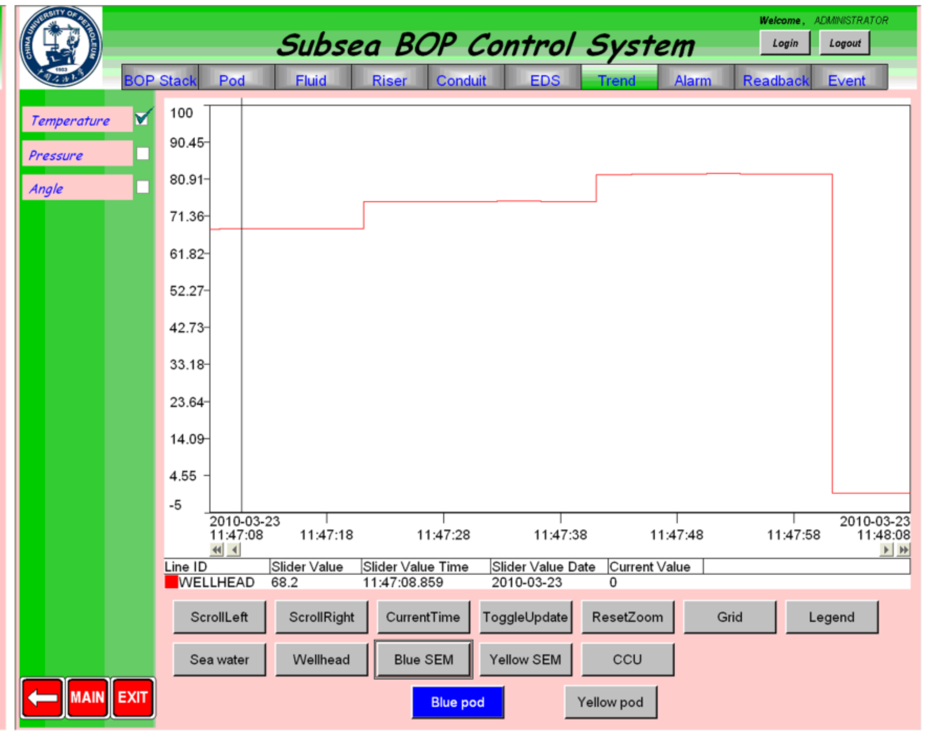
Subsea BOP stacks main control screen

PLC screen

1. Subsea systems

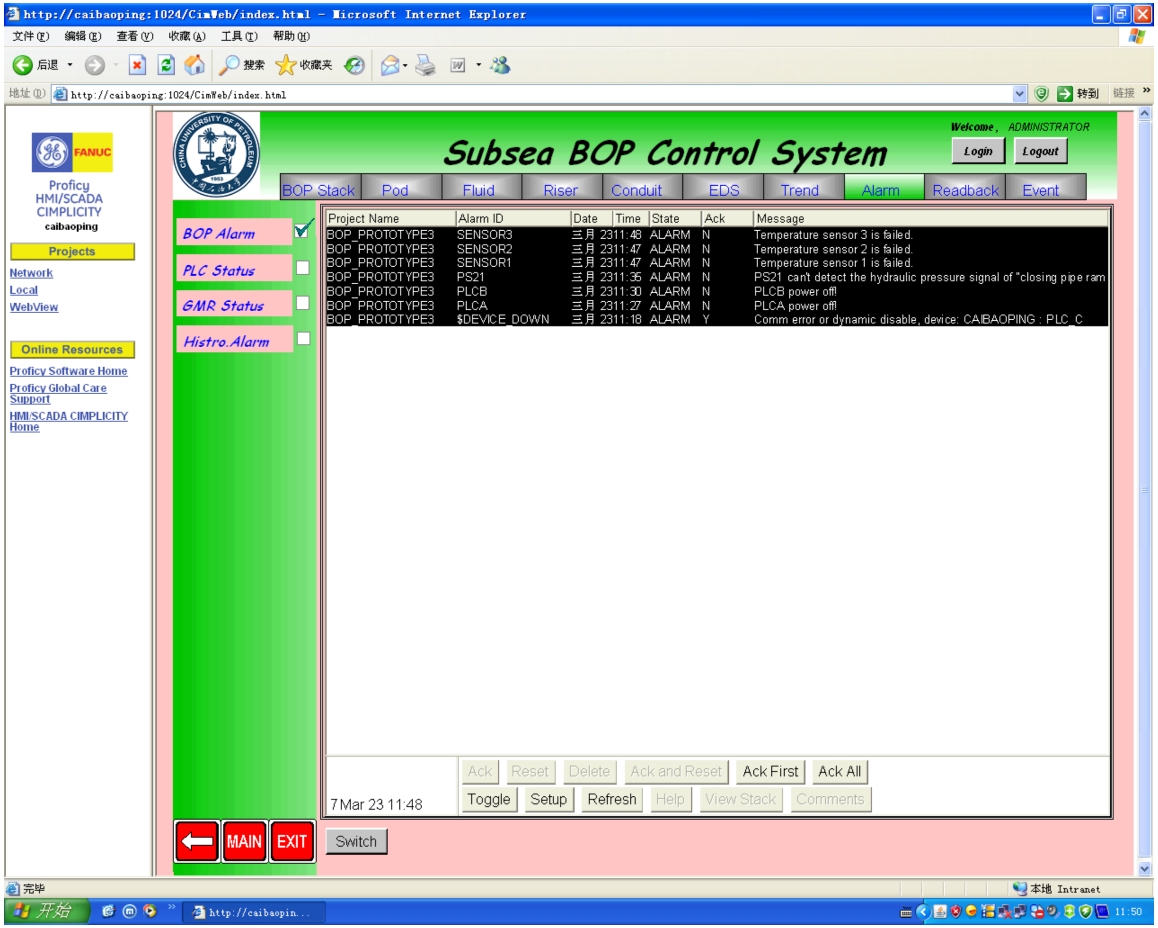


Pipe ram control screen



Data screen

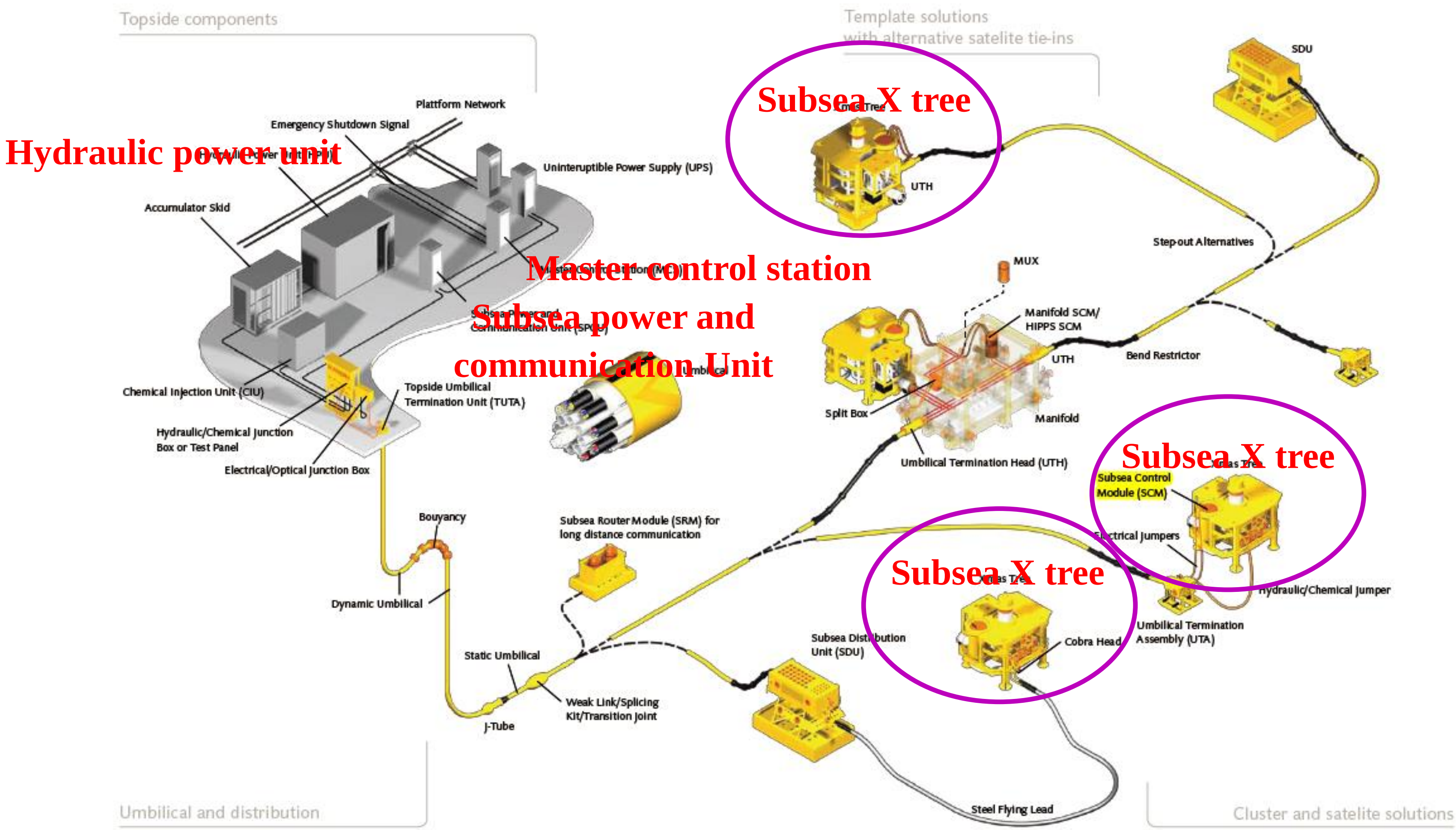
1. Subsea systems



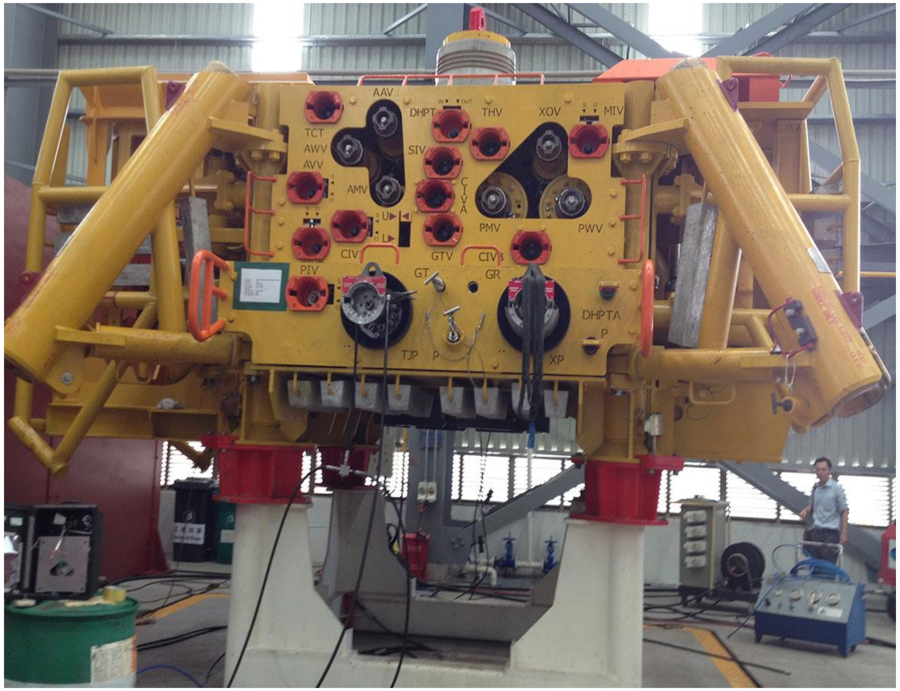
Remote monitoring alarm screen

1. Subsea systems

1.2. Subsea all-electric tree system



1. Subsea systems



Electro-hydraulic tree by One Subsea

All-electric tree by Cameron

1. Subsea systems

1.3. Subsea X tree test system

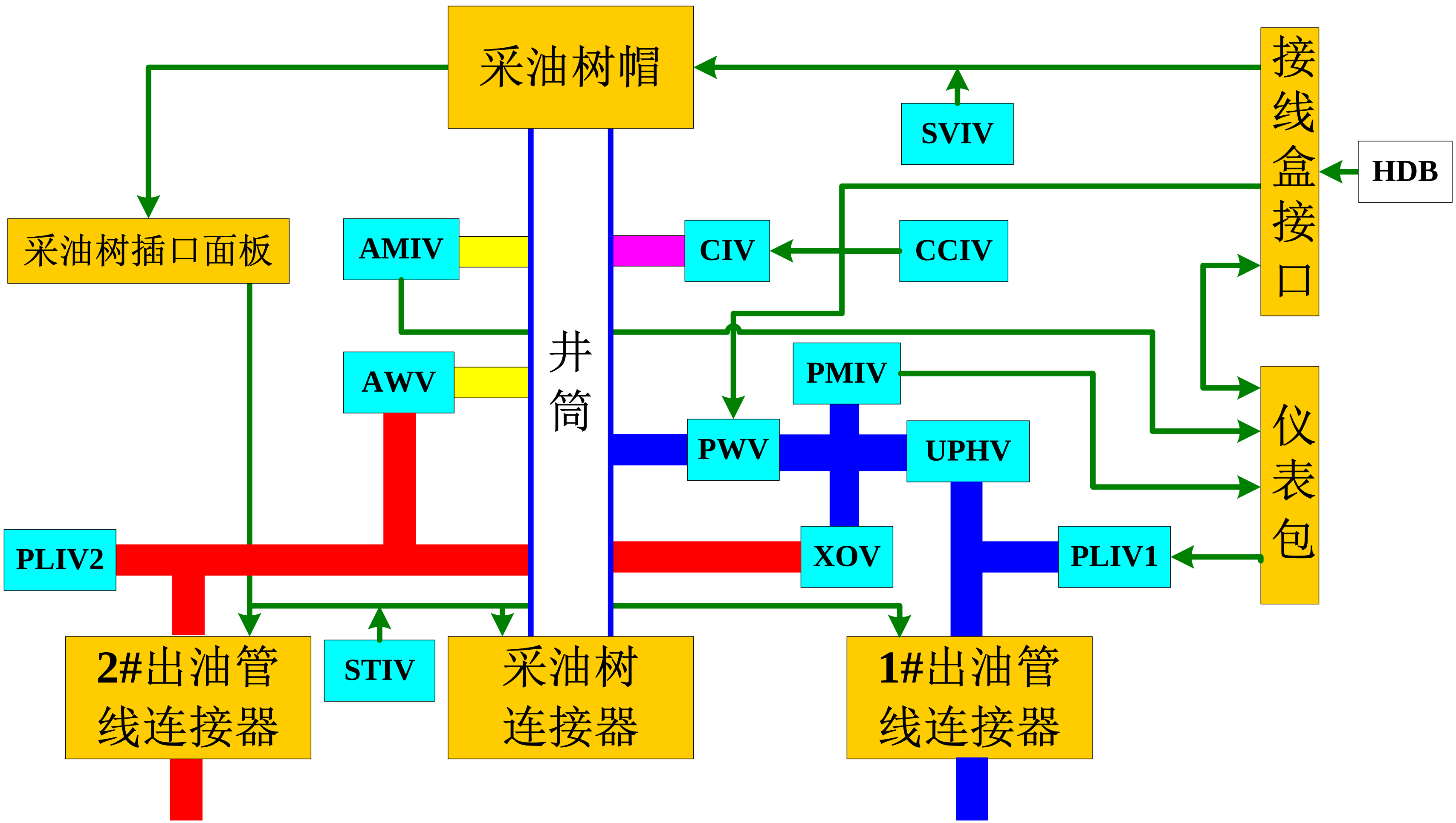
Liuhua 11-1/4-1 oil filed in South China Sea

1. Subsea systems

1.3. Subsea X tree test system

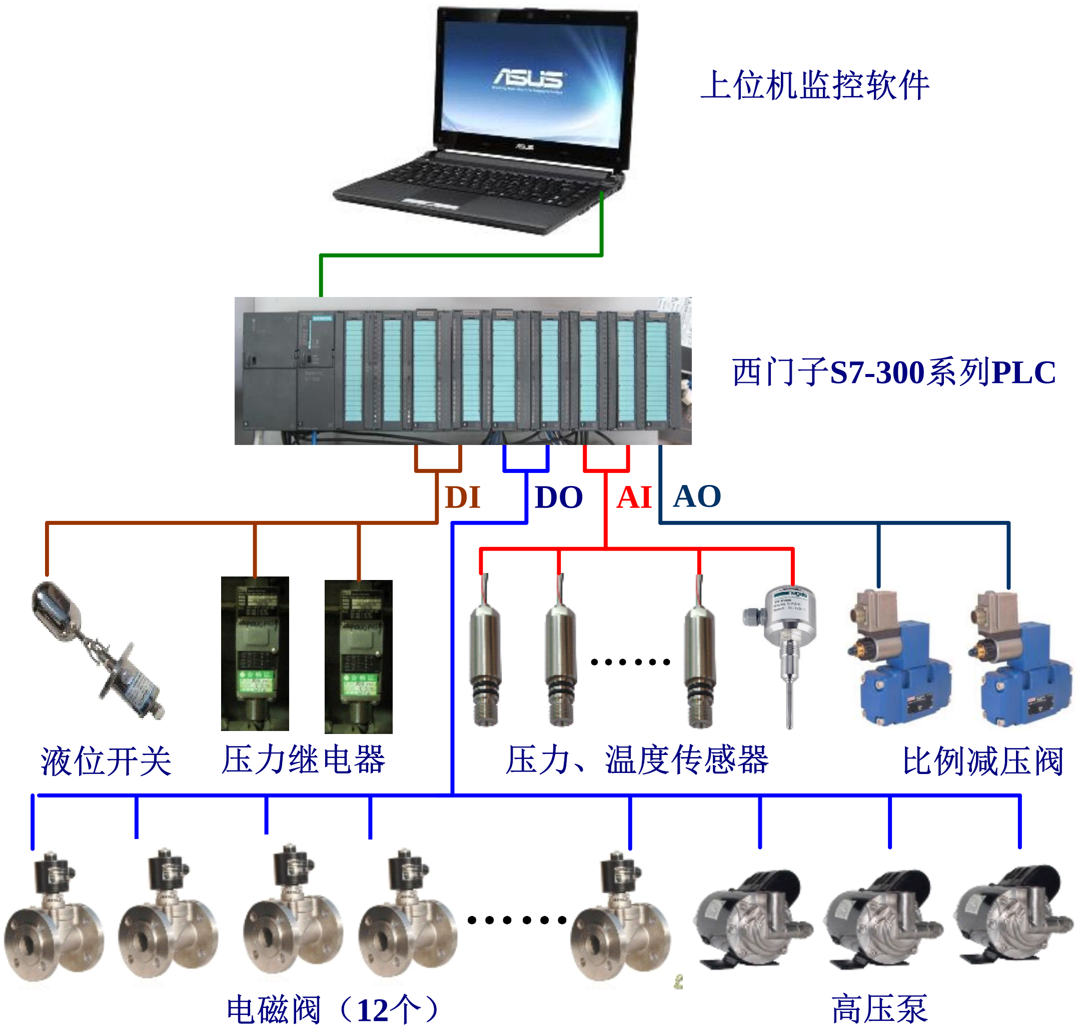
Subsea hydraulic tree in Liuhua 11-1 oil

1. Subsea systems



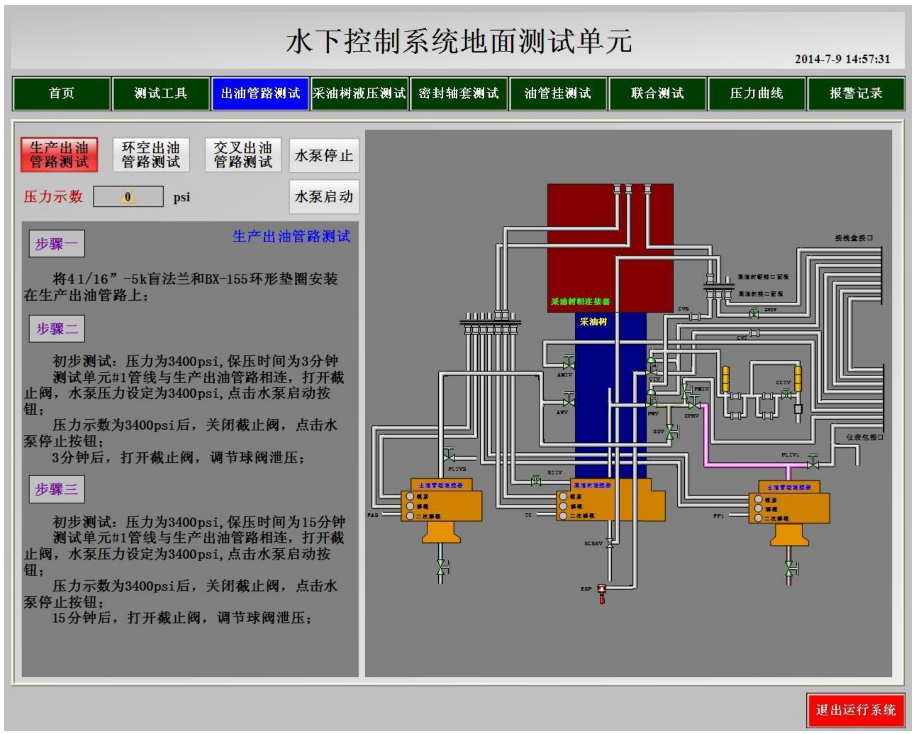
Schematic diagram of the subsea X tree

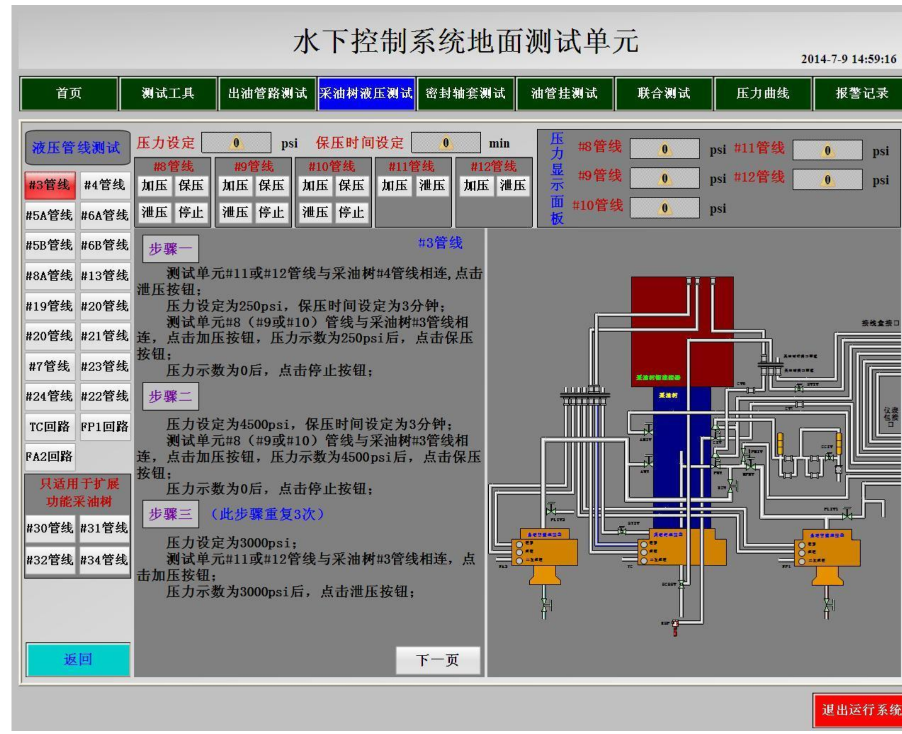
1. Subsea systems



Control system of the subsea X tree test platform

1. Subsea systems



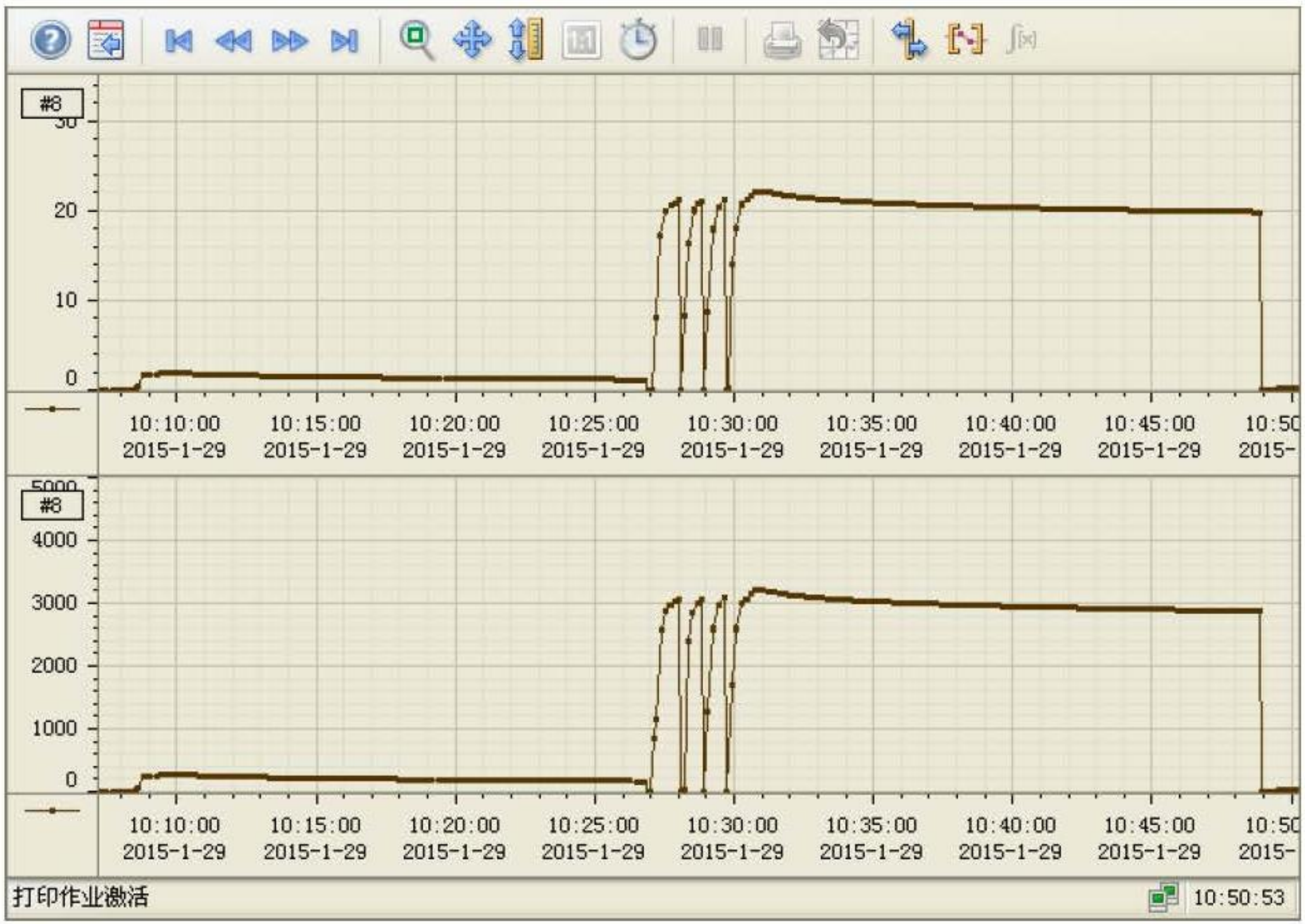


Screen of the subsea X tree test system

1. Subsea systems

Screen of the subsea X tree test system

1. Subsea systems



Detected pressure trend for a certain pipeline

Contents

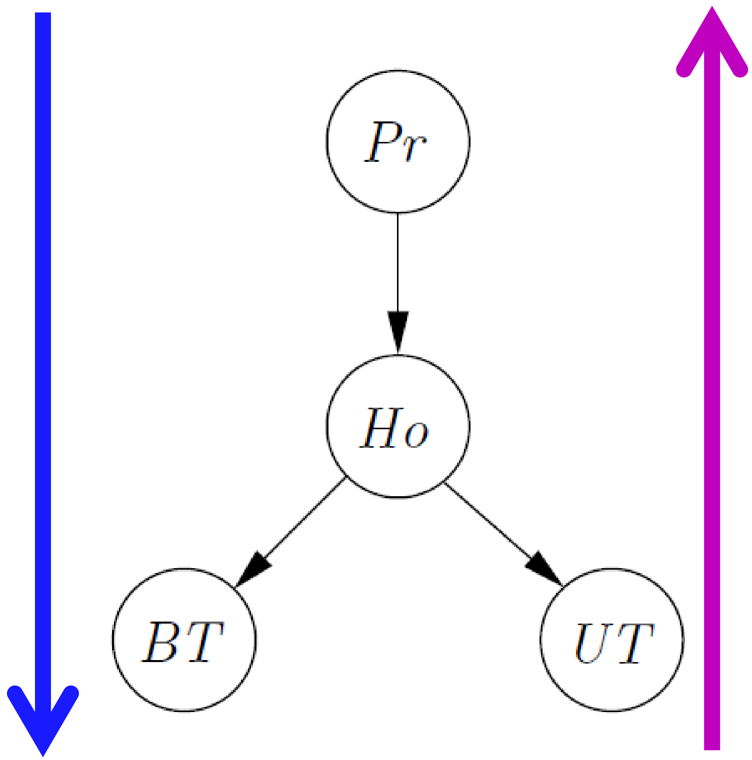
- 1. Subsea systems
- 2. Reliability methodology
- 3. Fault diagnosis methodology

2. Reliability methodology

What can BNs do?

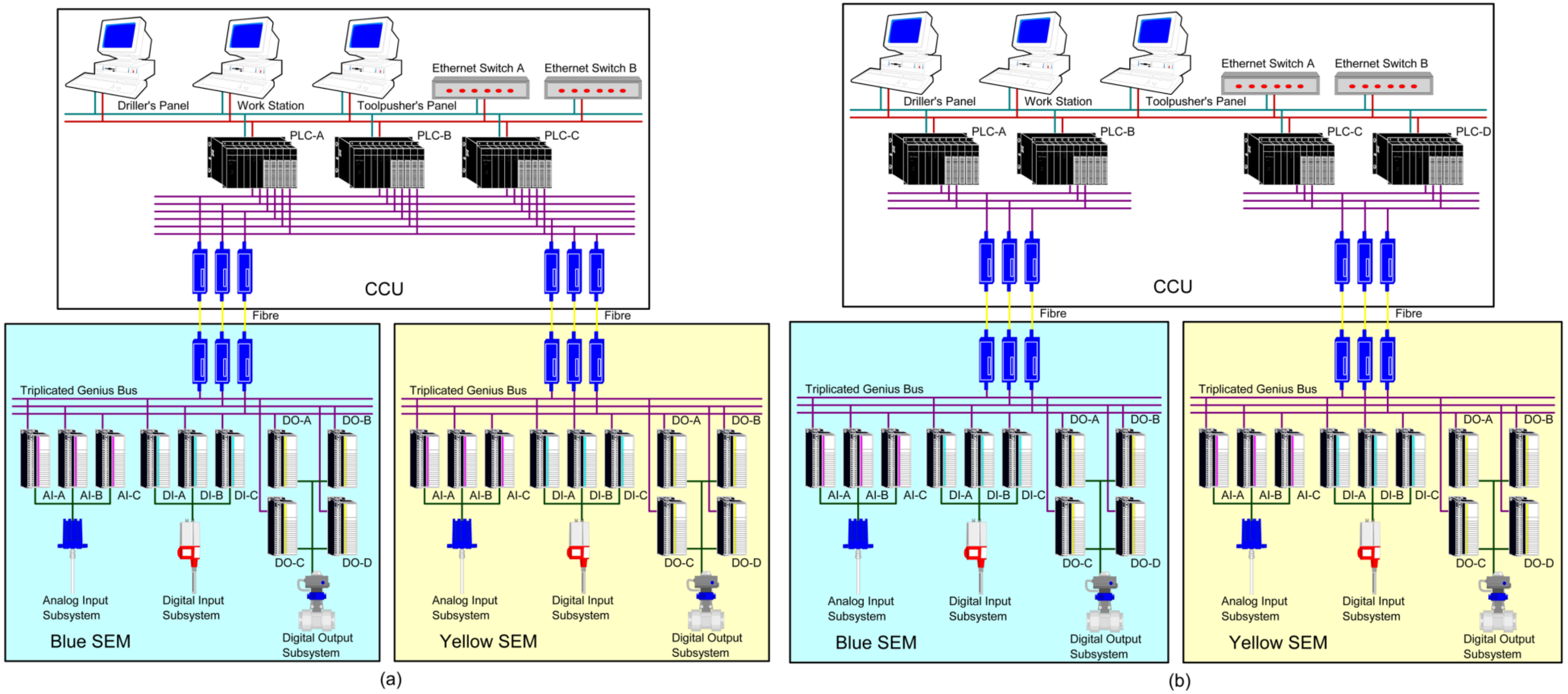
✓ BN can perform **forward or predictive analysis** as well as **backward or diagnostic analysis**.

Forward:
Predictive
Such as:
- ➢ Reliability
- ➢ Risk
- ➢ Safety



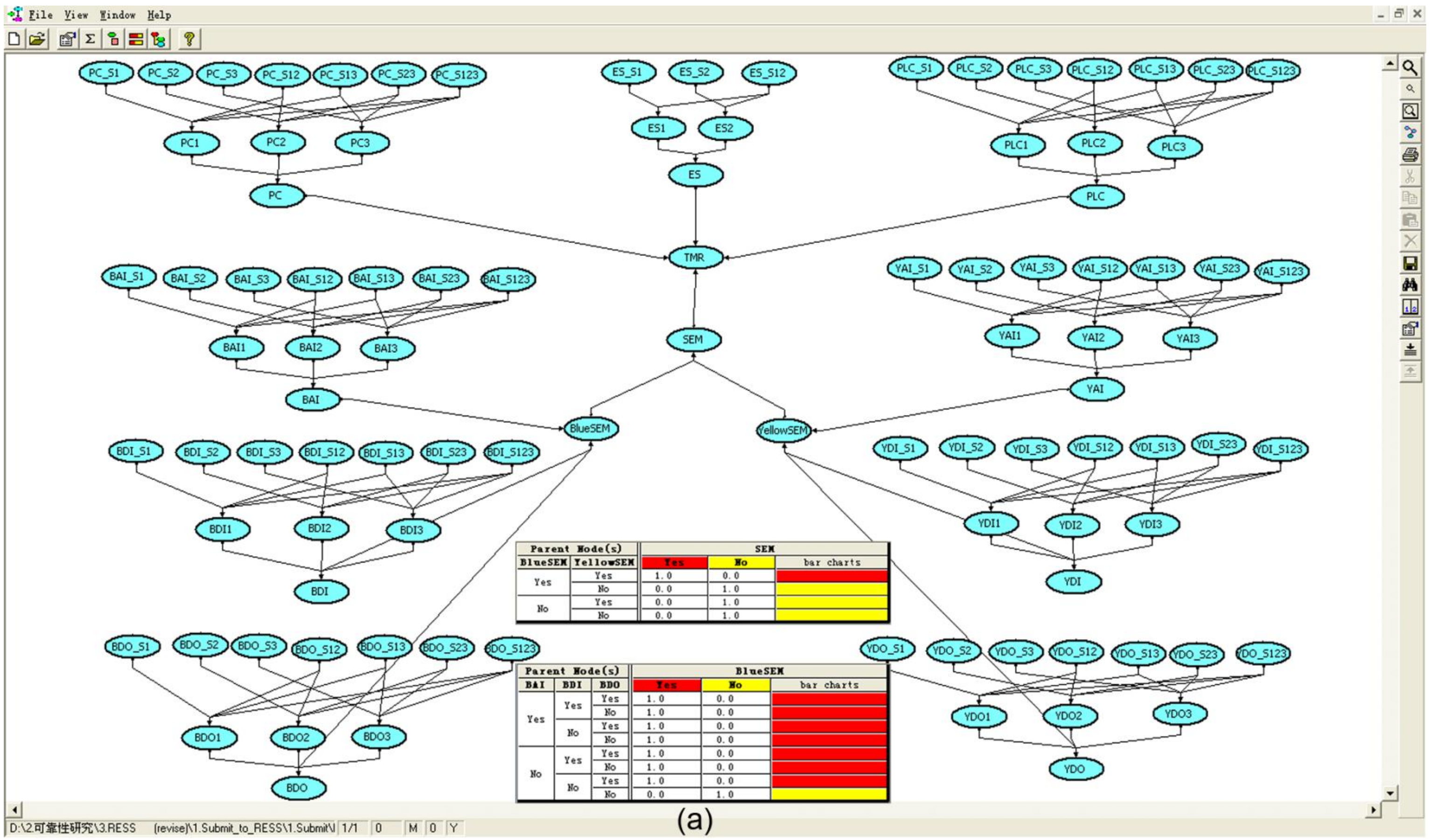
Backward:
Diagnostic
Such as:
- ➢ Fault diagnosis
- ➢ Disease diagnosis

2. Reliability methodology



Configurations of Triple Modular Redundancy (TMR) and Double Dual Modular Redundancy (DDMR) control systems for subsea BOP

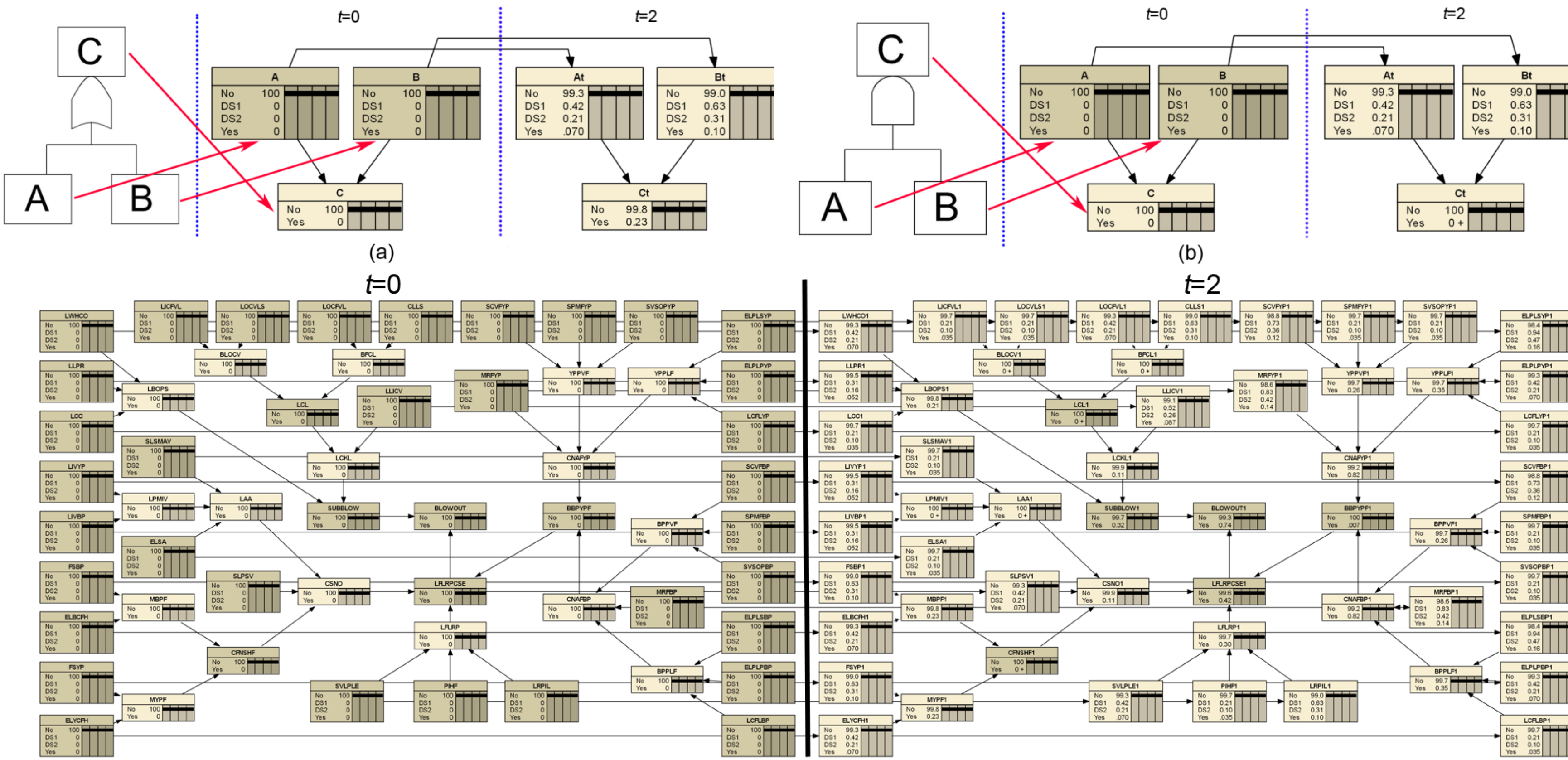
2. Reliability methodology



(a)

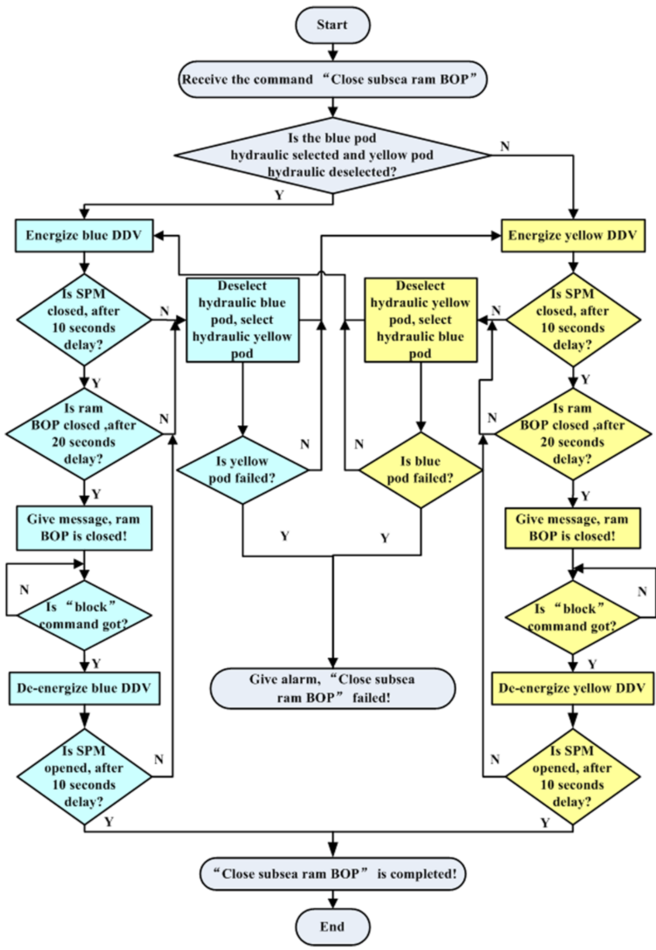
Using Bayesian networks in reliability evaluation for subsea blowout preventer TMR and DDMR control system, taking account of common cause failure and imperfect coverage (Cai, RESS, 2012).

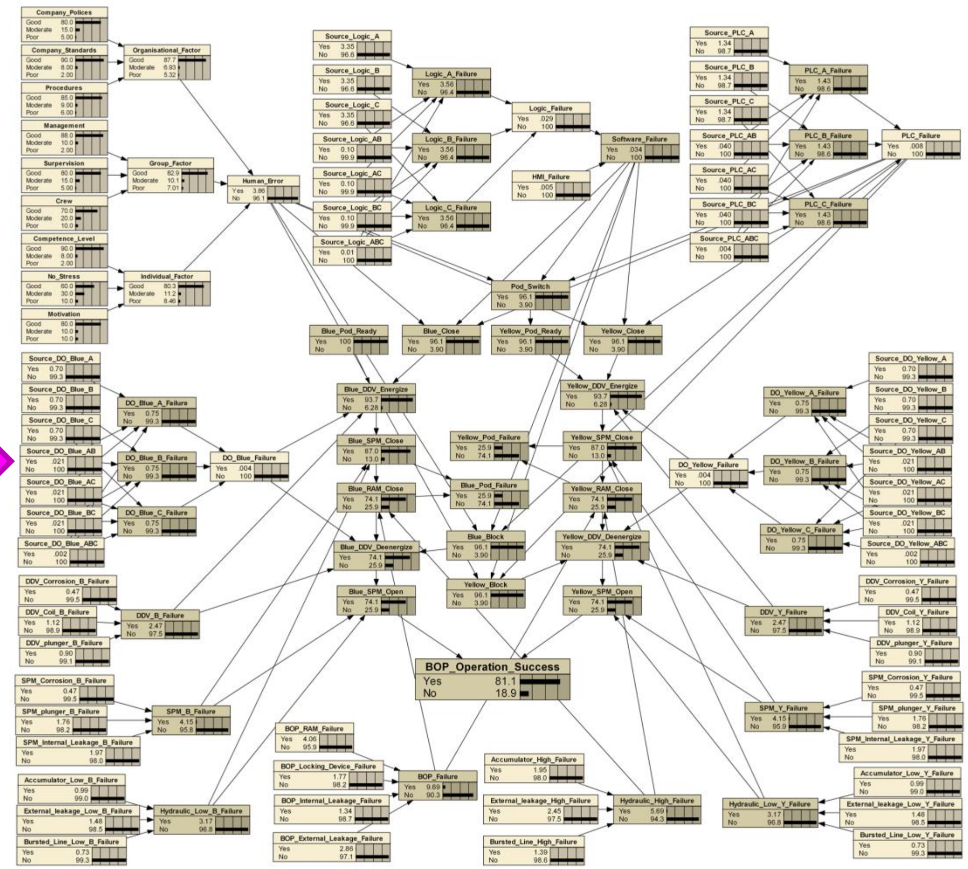
2. Reliability methodology



Performance evaluation of subsea BOP/control systems using dynamic Bayesian networks with imperfect repair and preventive maintenance (Cai, ESWA, 2012; Cai, EAAI, 2012)

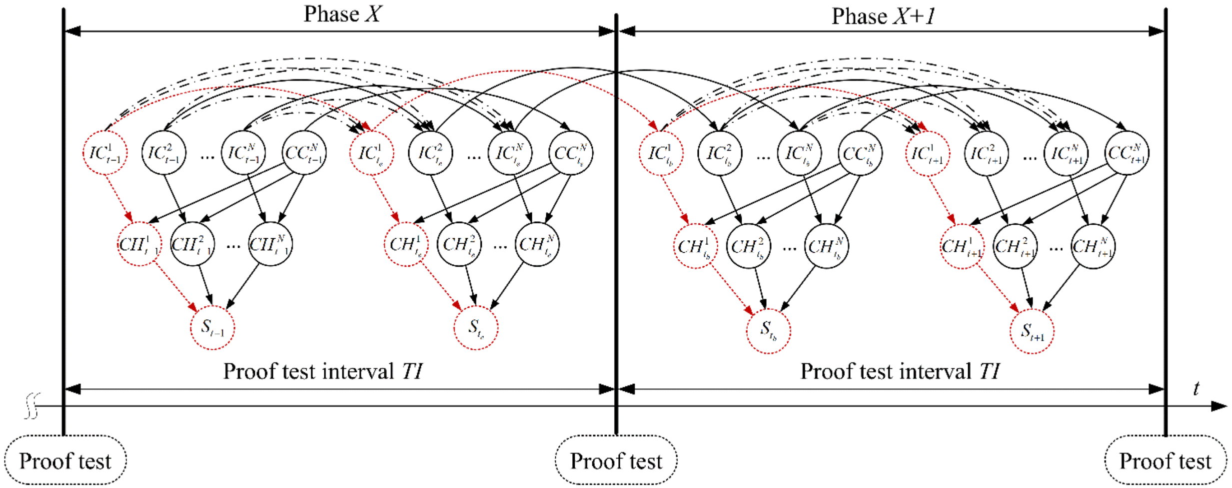
2. Reliability methodology

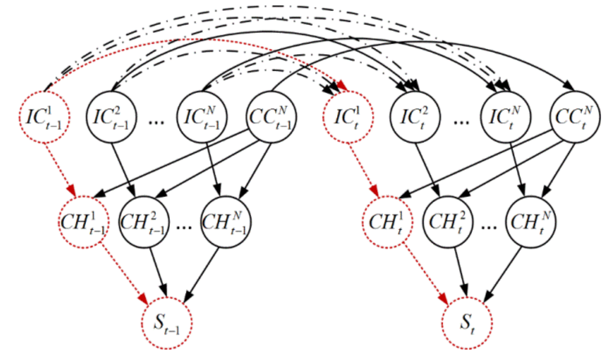




Application of Bayesian Networks in Quantitative Risk Assessment of Subsea Blowout Preventer Operations (Cai, RA, 2013)

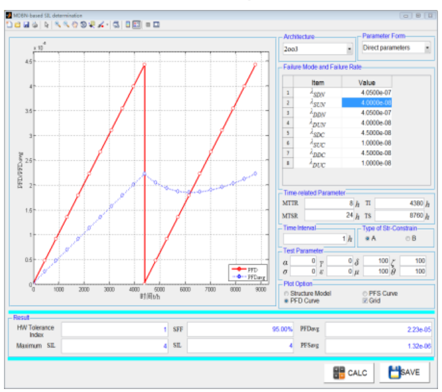
2. Reliability methodology

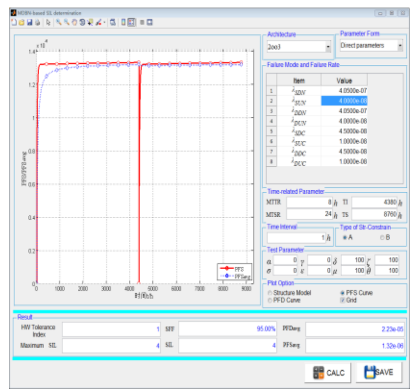


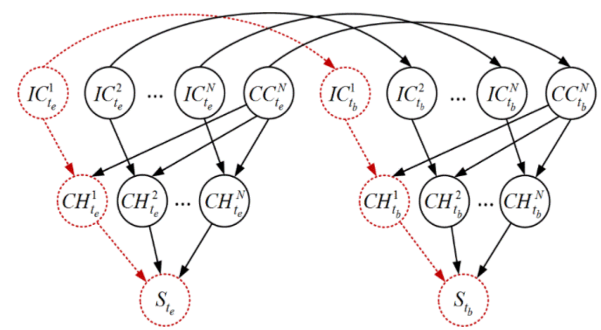


DBNs for proof test interval phase

Schematic diagram of MDBNs for SIL determination



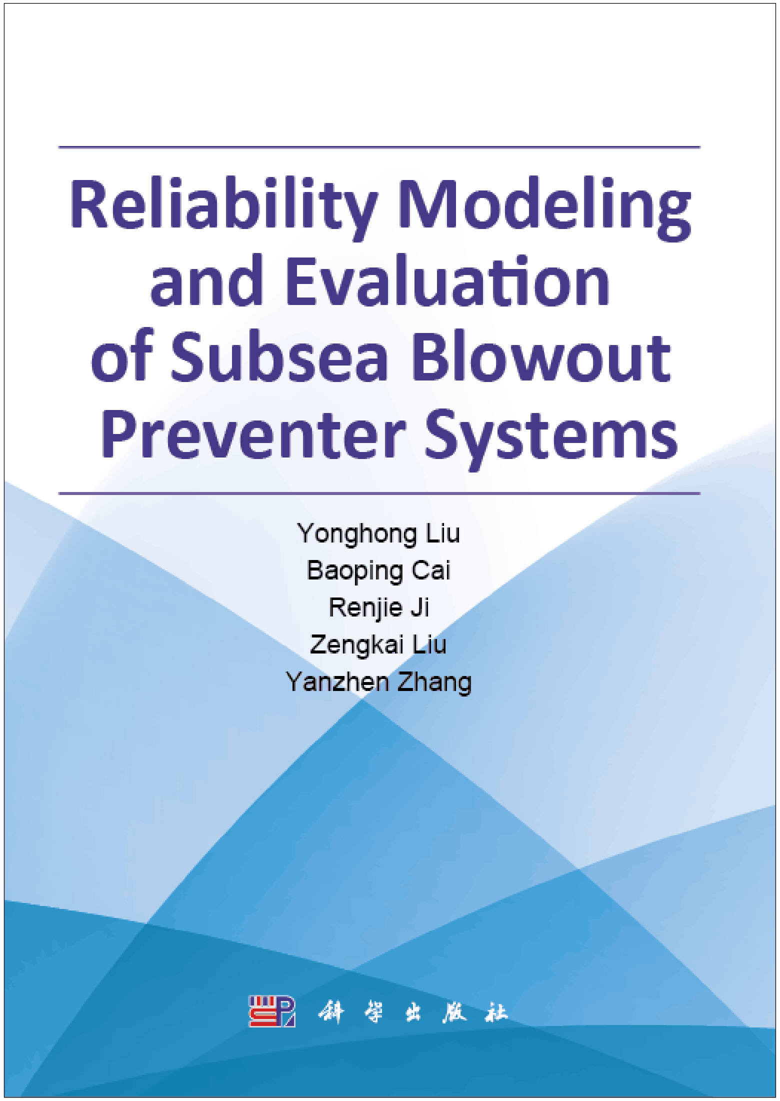




DBNs for proof test phase

A multiphase dynamic Bayesian networks methodology for the determination of safety integrity levels (Cai, RESS, 2016)

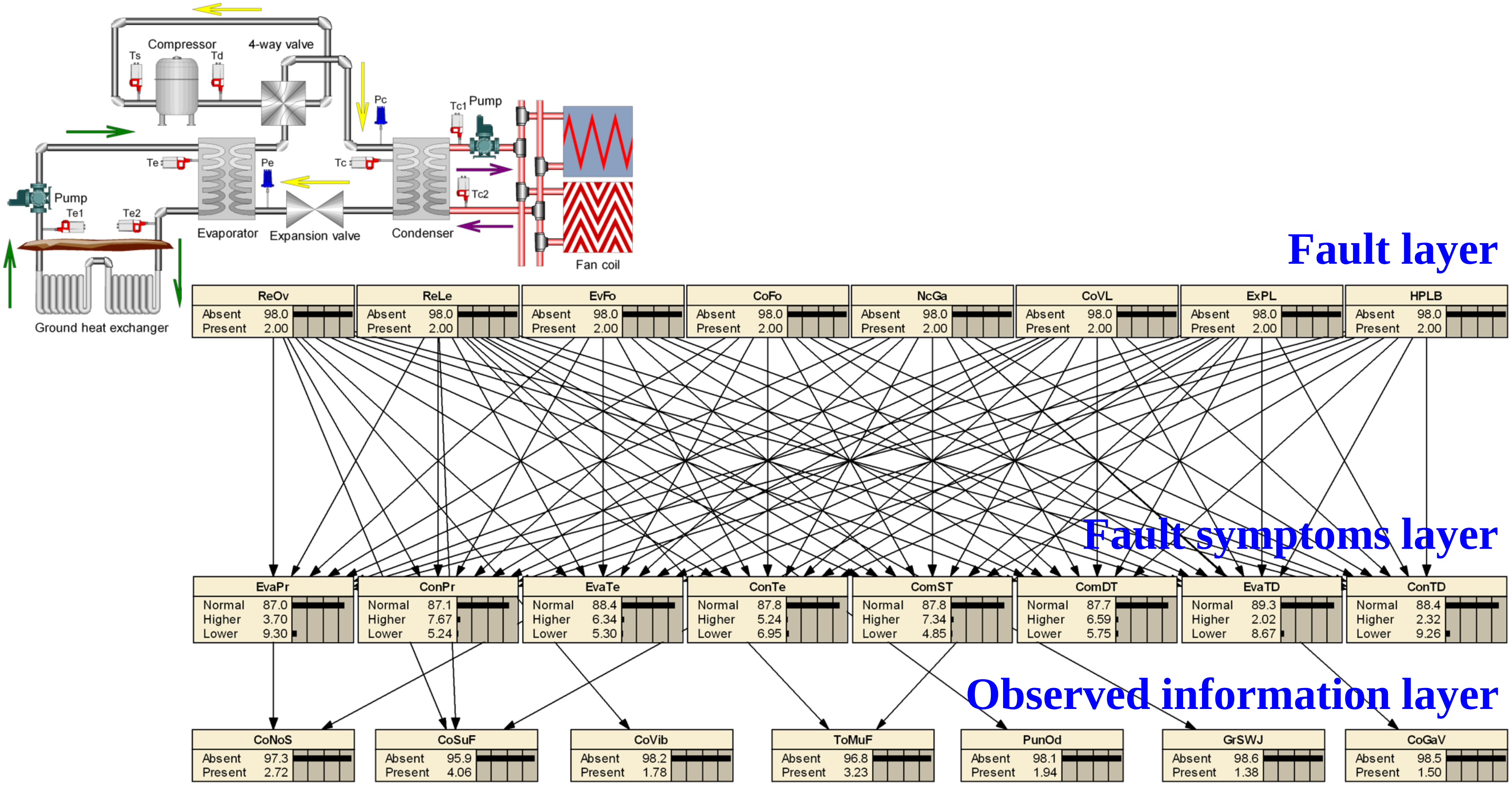
2. Reliability methodology



Contents

- 1. Subsea systems
- 2. Reliability methodology
- 3. Fault diagnosis methodology

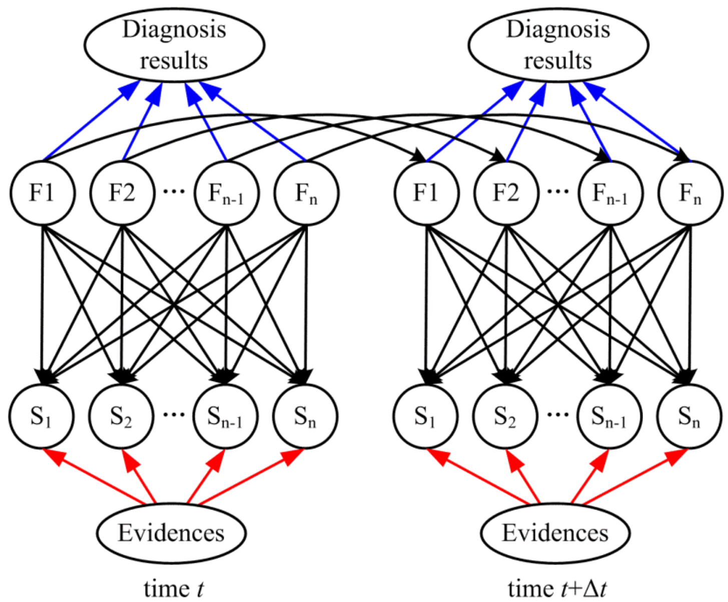
2. Procedures of FD with BNs



Structure of BNs for FD of ground-source heat pump (Cai, APEN, 2014)

3. Types of BNs for FD

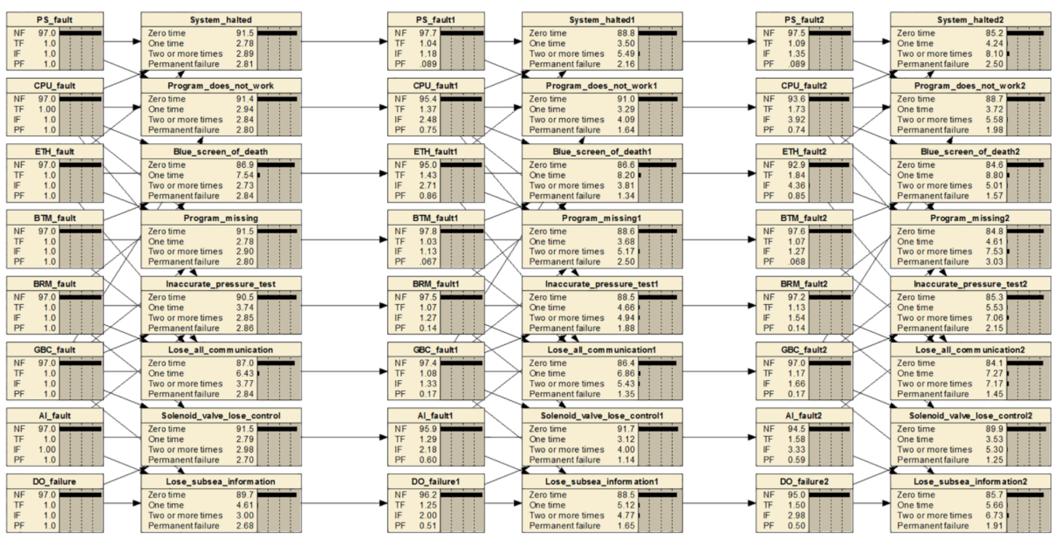
3.2. DBNs for fault diagnosis



DBN-based fault diagnosis model for GMR control systems (Cai, TASE, 2016)

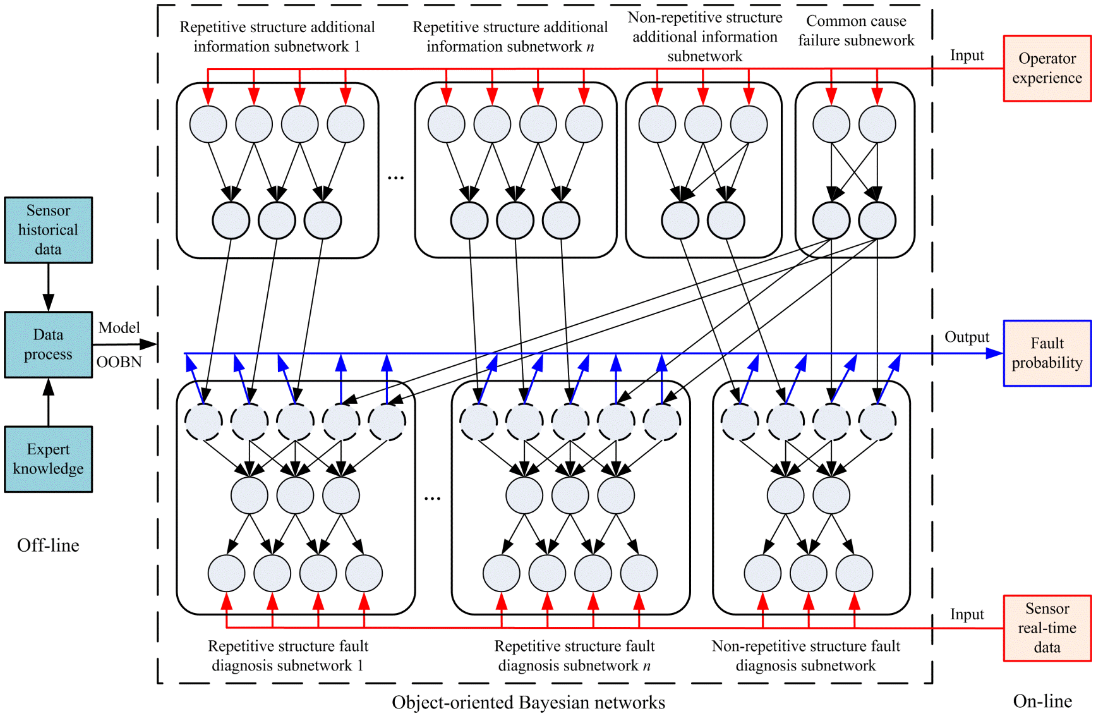
Given same fault symptoms, the diagnostic result may be totally different in different time periods because of the performance degradation of components.

In other words, a new system is more likely to work well than an aged system in a next time point if it works well at present time. It can increase the accuracy and reliability of fault diagnosis by involving the dynamic and temporal features in fault diagnosis models.

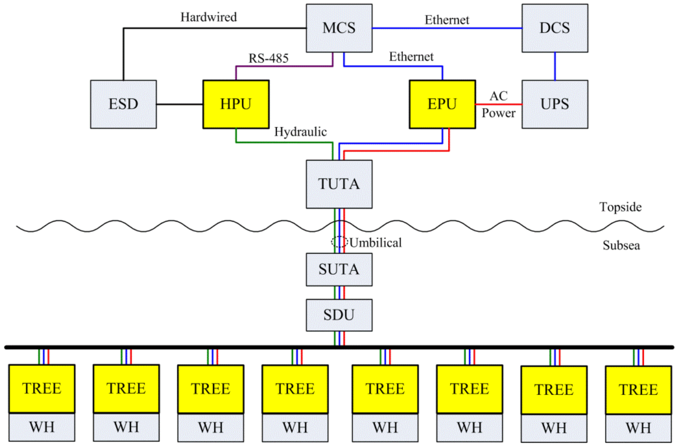


3. Types of BNs for FD

3.3. OOBNs for fault diagnosis



Object-oriented-BN-based fault diagnosis modeling methodology (Cai, MSSP, 2016)



OOBNs have the following advantages:

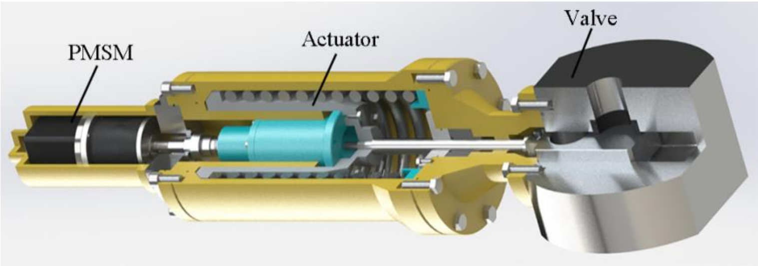
(1) supports top-down model construction process;

(2) are constructed by integrating small and understandable network fragments, benefiting knowledge acquisition and communication between modelers and domain experts;

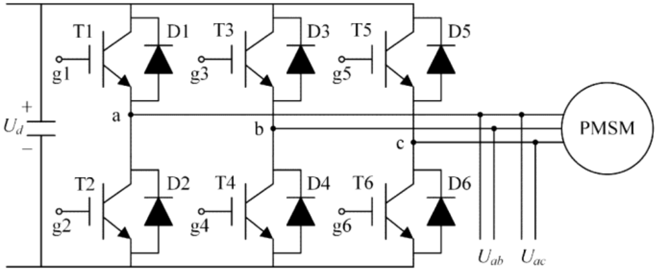
(3) reduces the complexity of building BNs, and improves the reusability of models;

(4) have high average rate of convergence and time efficiency thanks to the characteristic of encapsulation and hierarchy.

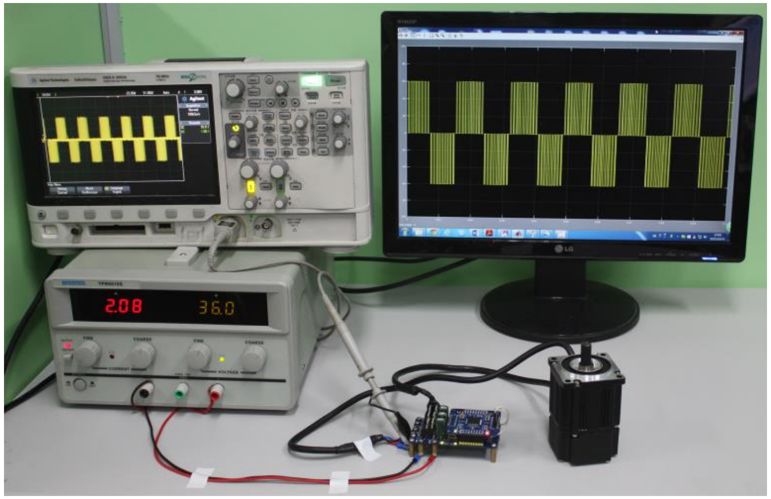
2. Procedures of FD with BNs



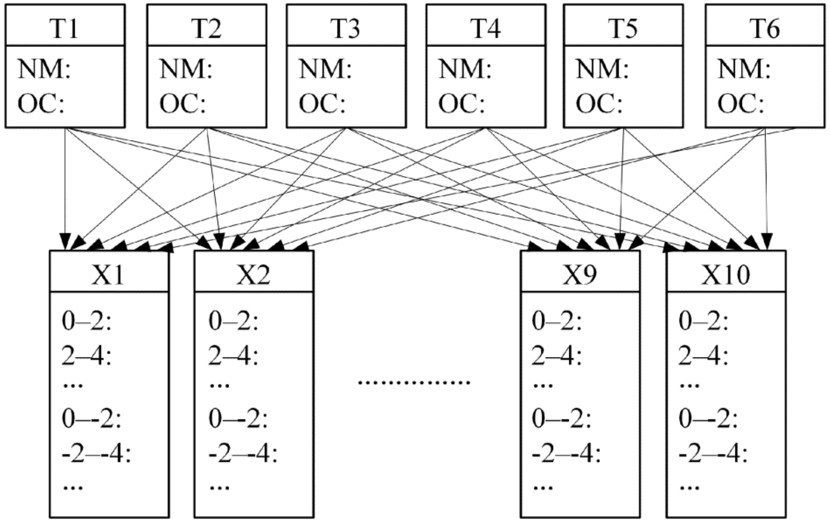
Subsea electric actuator



Topology of a typical three-phase inverters



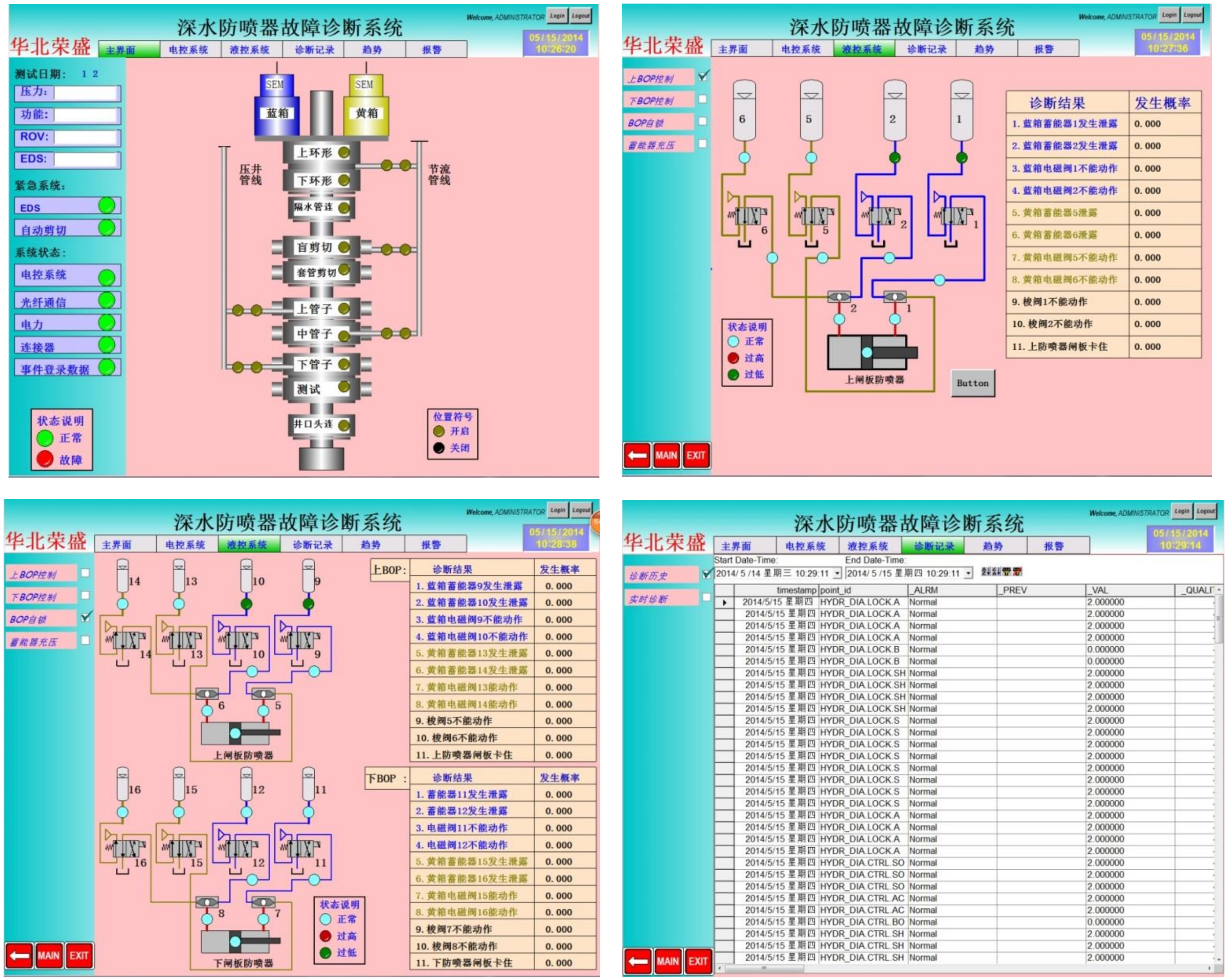
Experimental setup of the PMSM drive system



Two-layers BNs for fault diagnosis

A Data-Driven Fault Diagnosis Methodology in Three-Phase Inverters for PMSM Drive Systems (Cai, TPE, 2016)

3. Fault diagnosis



Subsea BOP fault diagnosis system

3. Fault diagnosis

Future research directions of FD:

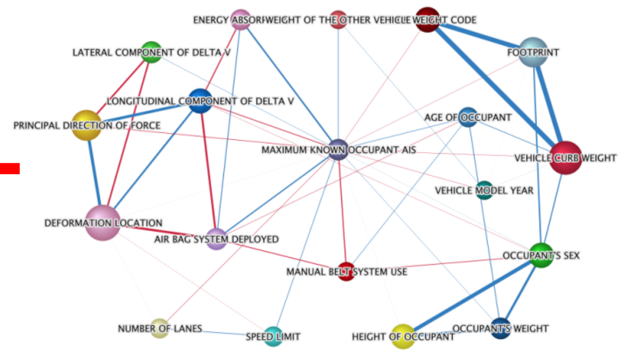
1. **Integrated big data and BNs FD methodology**
2. **BN-based non-permanent FD**
3. **Fast inference algorithms of BNs for on-line FD**
4. **BNs for closed-loop control system FD**
5. **Fault identification rules**

Based the submitted review paper (Cai, TII)

6. Future research directions

6.1. FD methodology integrated big data and BNs

+



= FD

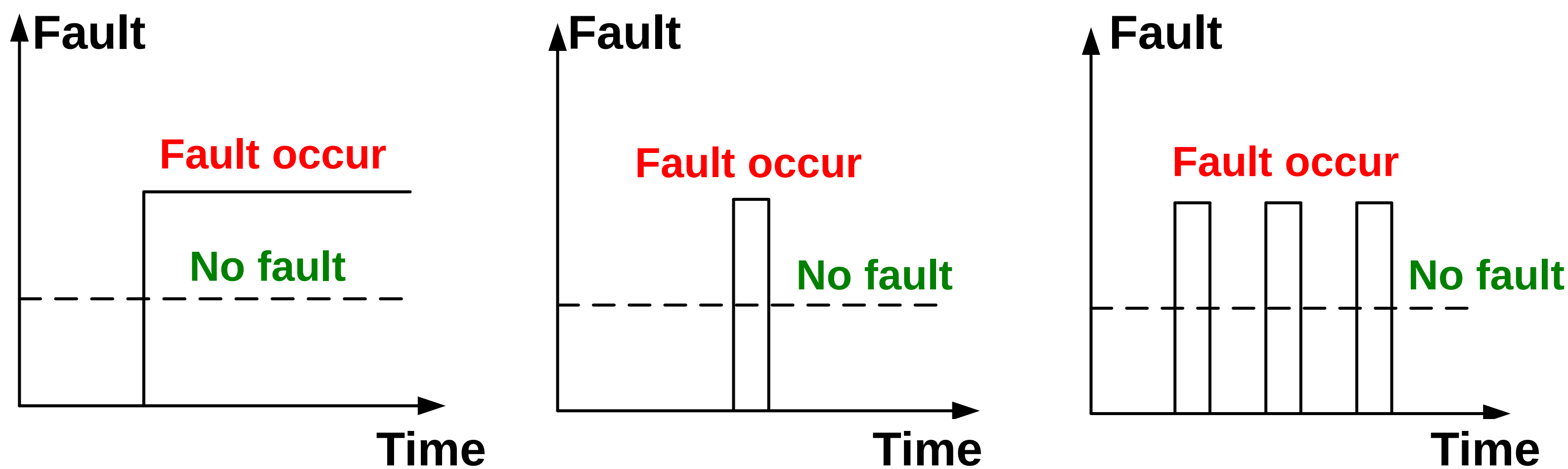
Two important parts:

✓ **Fault feature extraction method from big data;**

✓ **BN-based fault diagnosis method using theses fault features.**

6. Future research directions

6.2. BN-based non-permanent FD



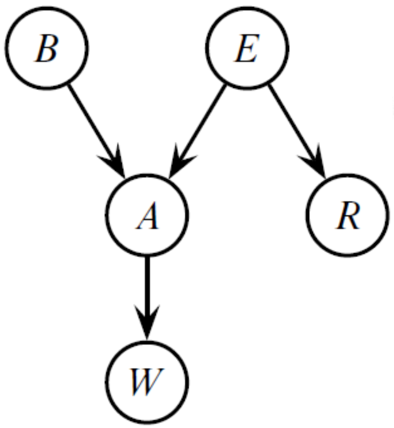
Permanent fault Transient fault Intermittent fault

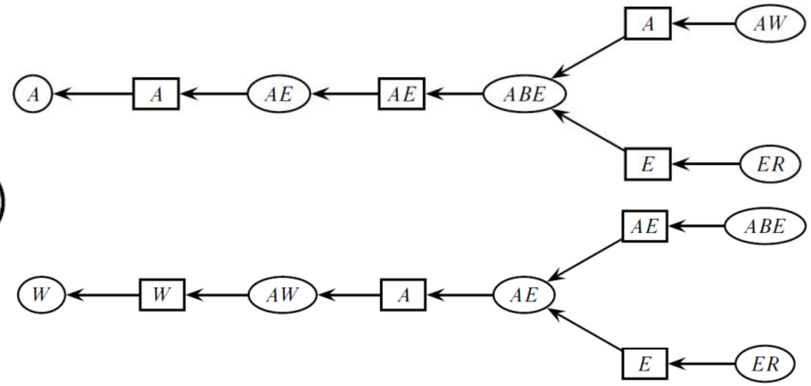
How to:

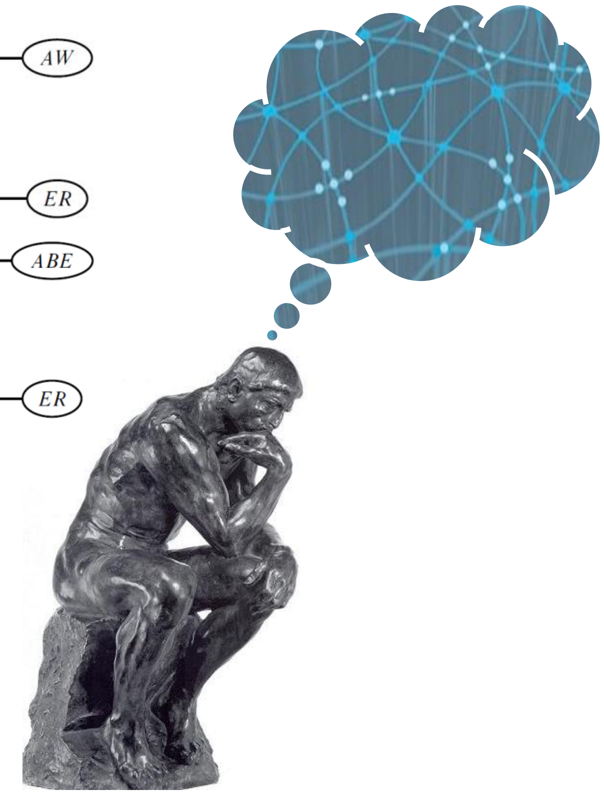
- ✓ Analyze the nature and the root causes;
- ✓ Identify the failed components;
- ✓ Distinguish the fault type using BN-based FD.

6. Future research directions

6.3. Fast inference algorithms of BNs for on-line FD







Traditional inference:

- **Becomes increasingly expensive;**
- **Costs lots of time;**
- **Hardly perform real-time FD.**

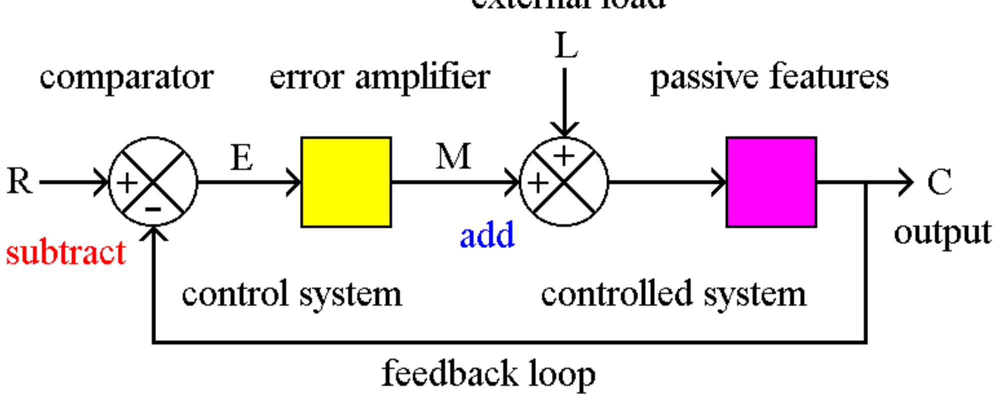
It is necessary to:

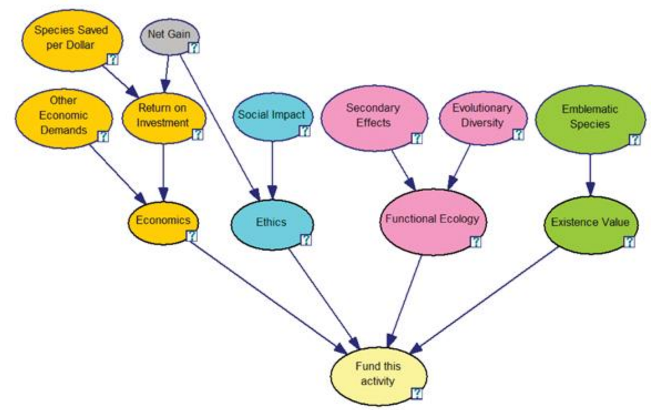
✓ **Develop fast approximate inference algorithms of BNs for on-line FD.**

6. Future research directions

6.4. BNs for closed-loop control system FD

Figure 1: basic control system





closed-loop control system

BN: acyclic directed graph

How to:

✓ **Establish the FD models of closed-loop feedback control systems with acyclic directed BNs**

✓ **Investigate the effects of control algorithm on FD**

6. Future research directions

6.5. Fault identification rules

False alarm rate is a significant assessment indicator for fault diagnosis, and high false alarm rate cannot be accepted by users of industrial systems.

Developing:

- ✓ **Suitable fault identification rules for a certain system, by**
  - ➢ **using posterior probability directly**
  - ➢ **integrated prior and posterior probability**


Thank you!