



Seminar in NTNU



Our recent research...

Dr. Baoping CAI

25 November 2016, Trondheim, Norway



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**

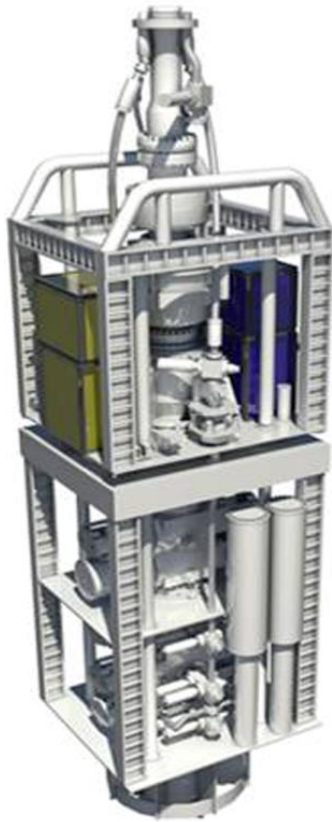


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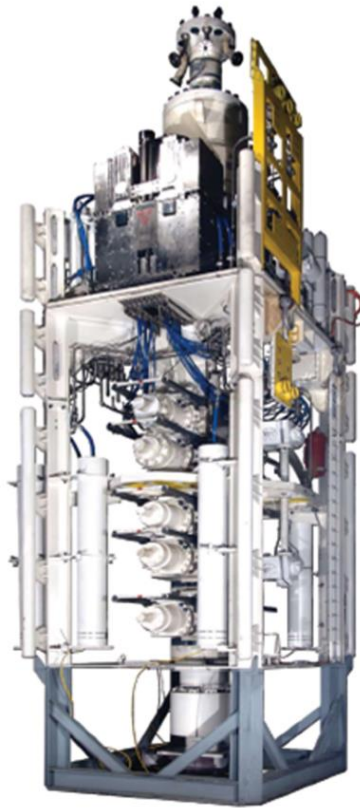


-
- **1. Subsea systems**
 - **2. Reliability methodology**
 - **3. Fault diagnosis methodology**

1.1. Subsea BOP system



Cameron



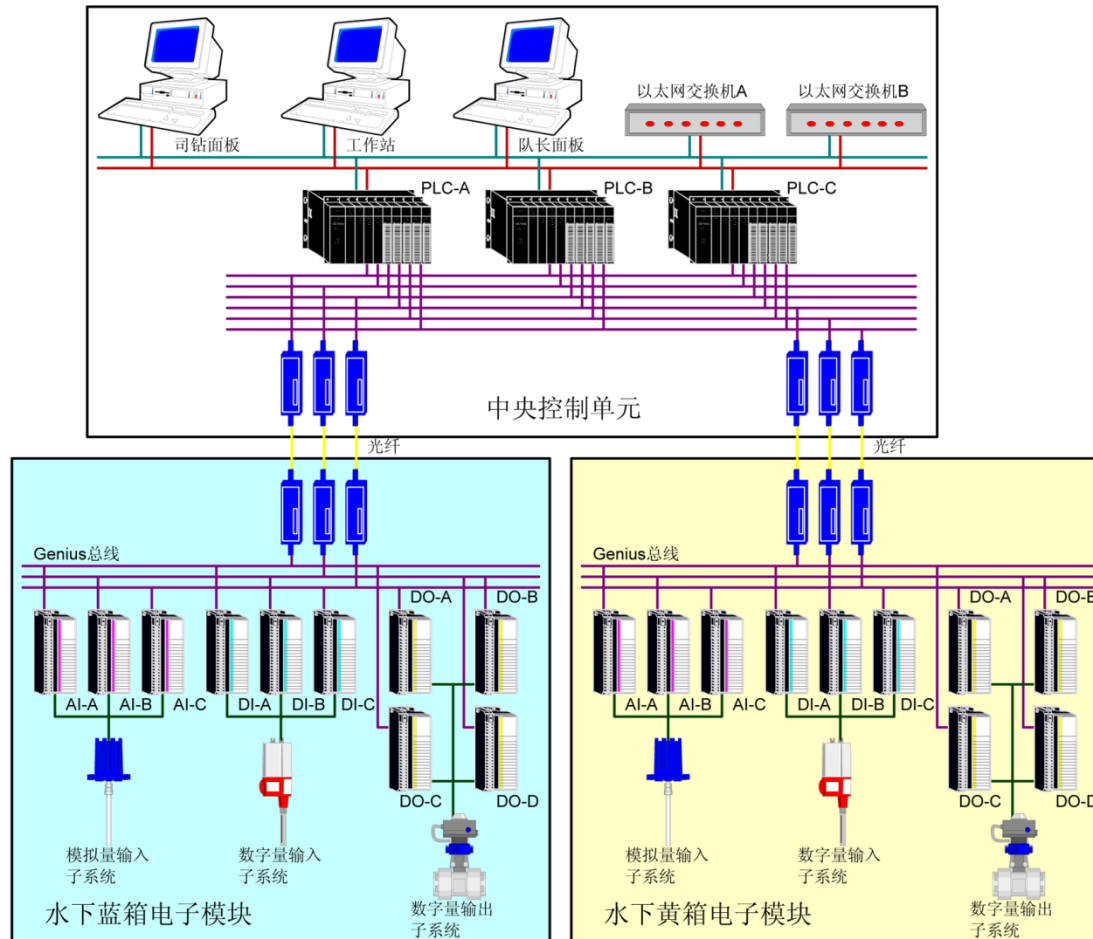
Hydril



NOV

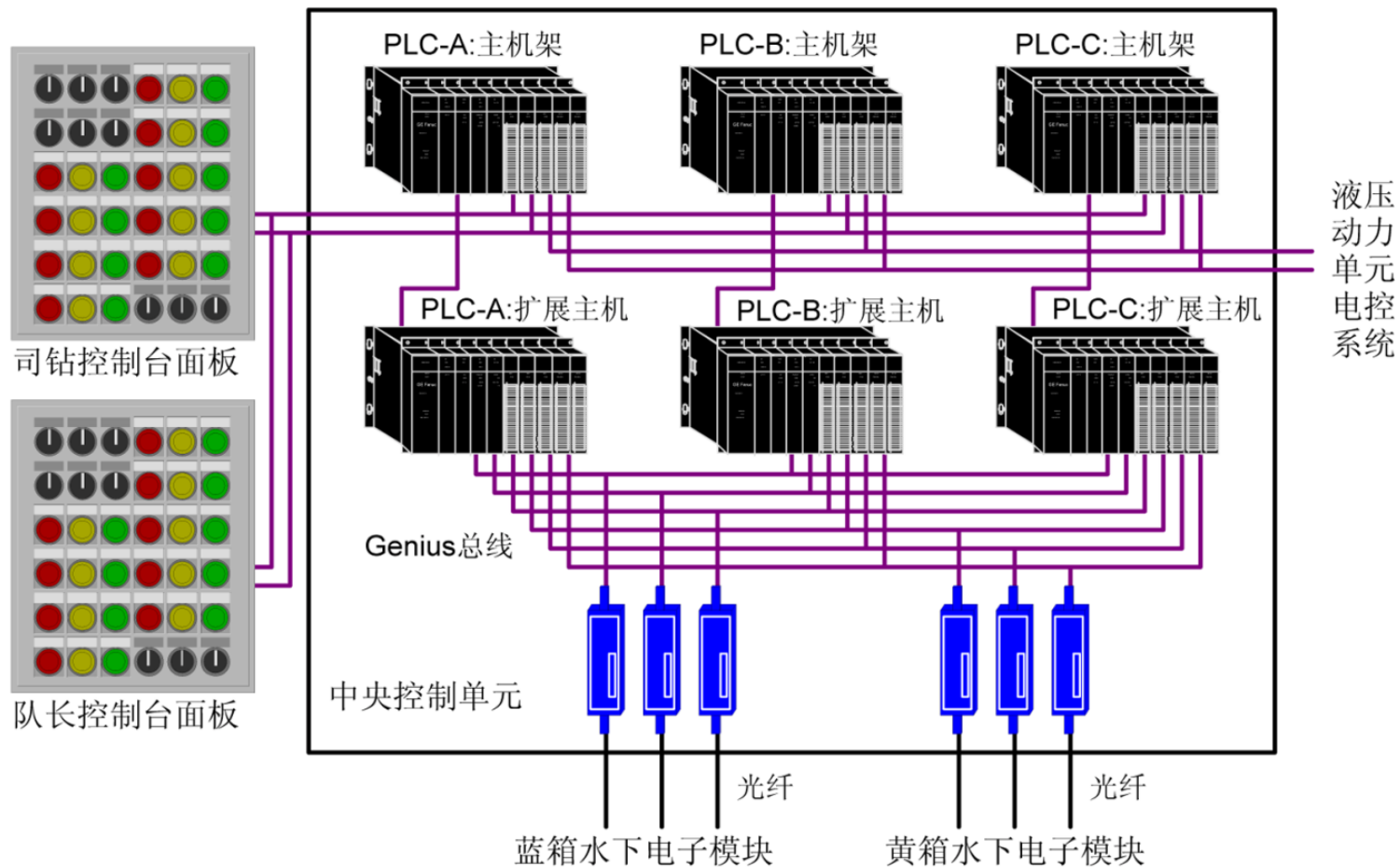
Deepwater subsea BOP systems

1. Subsea systems



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

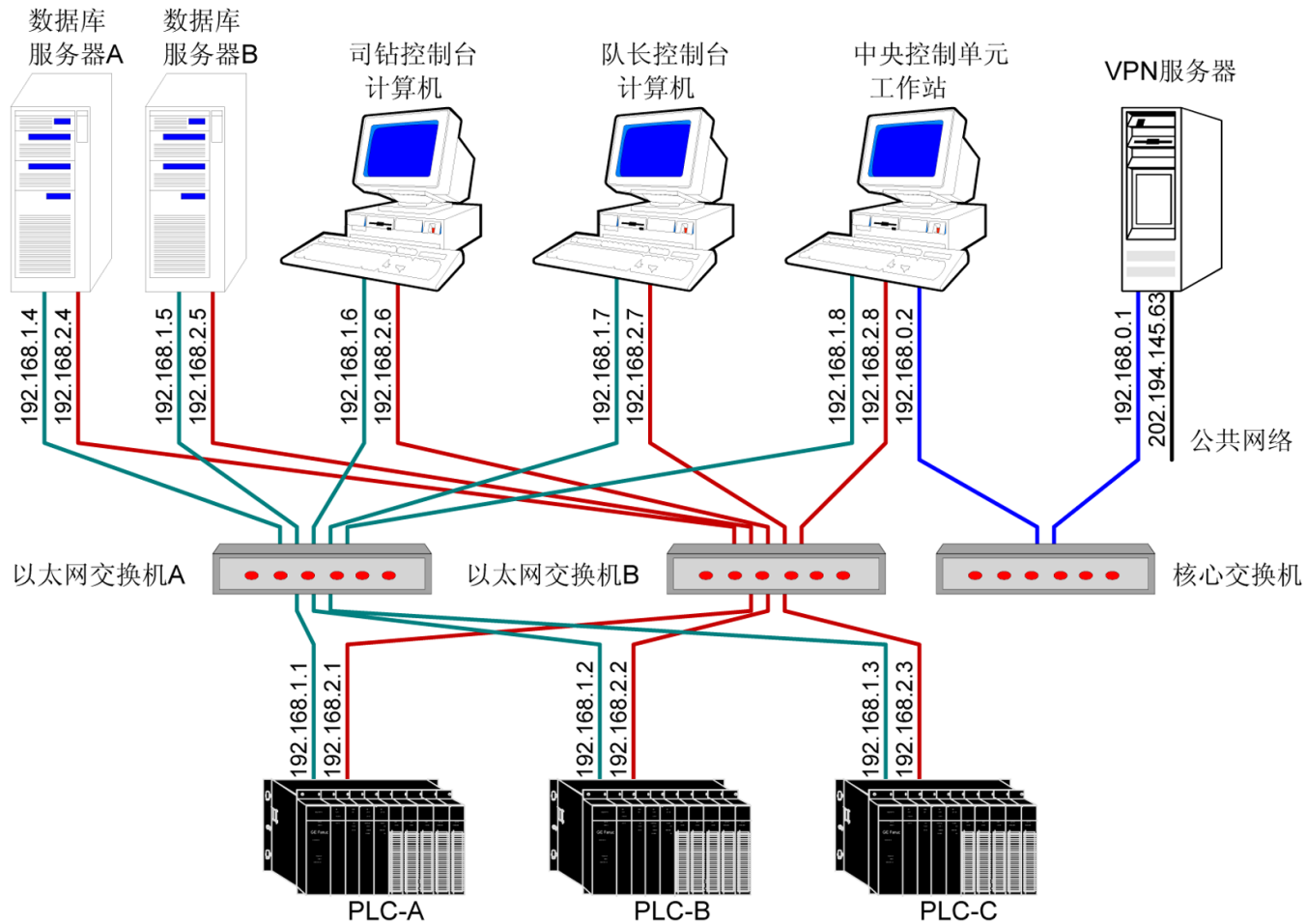
1. Subsea systems



System configuration of triple redundant controller

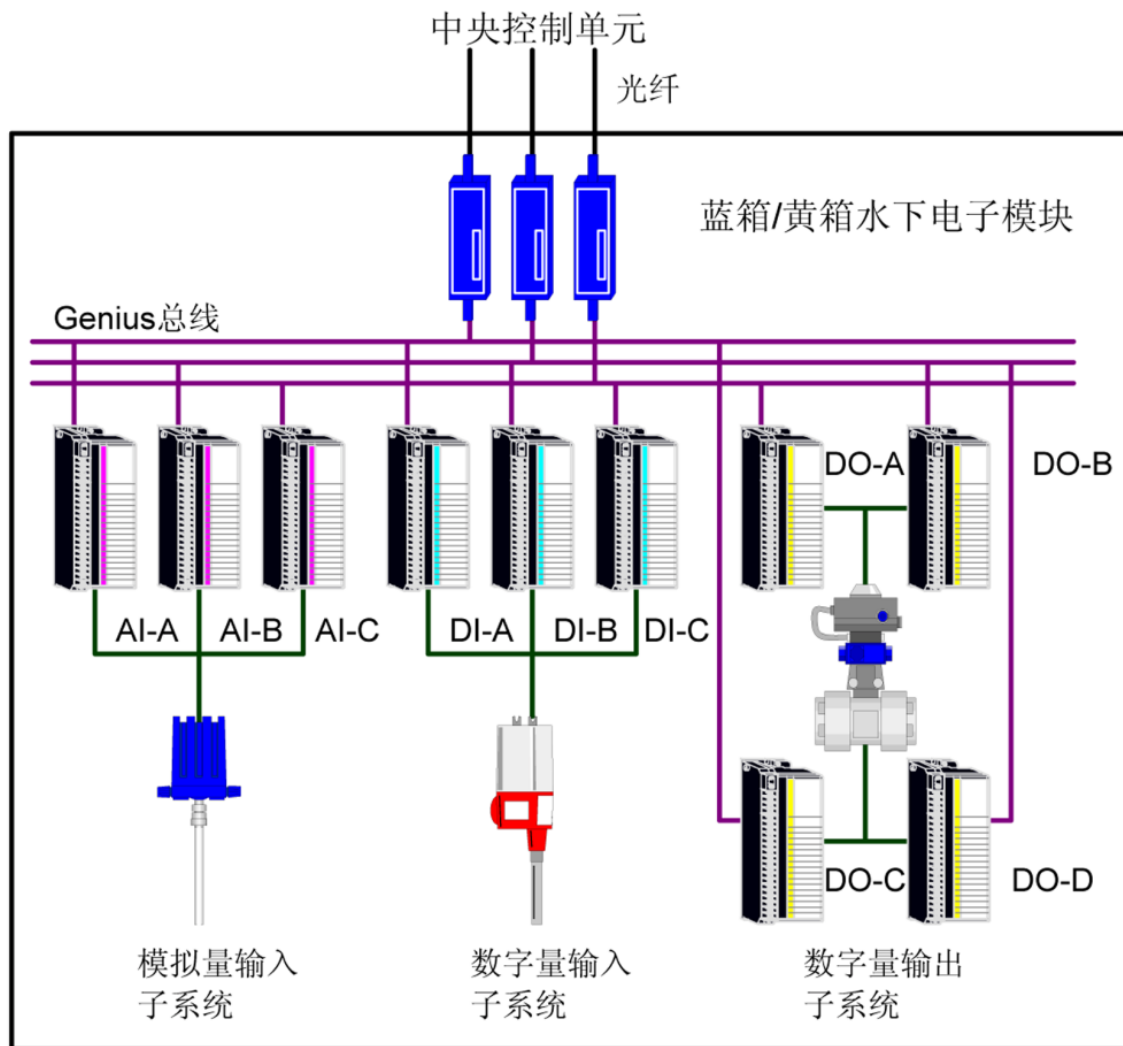


1. Subsea systems



Architecture of dual redundant Ethernet.

1. Subsea systems



Subsea electronic module (SEM)

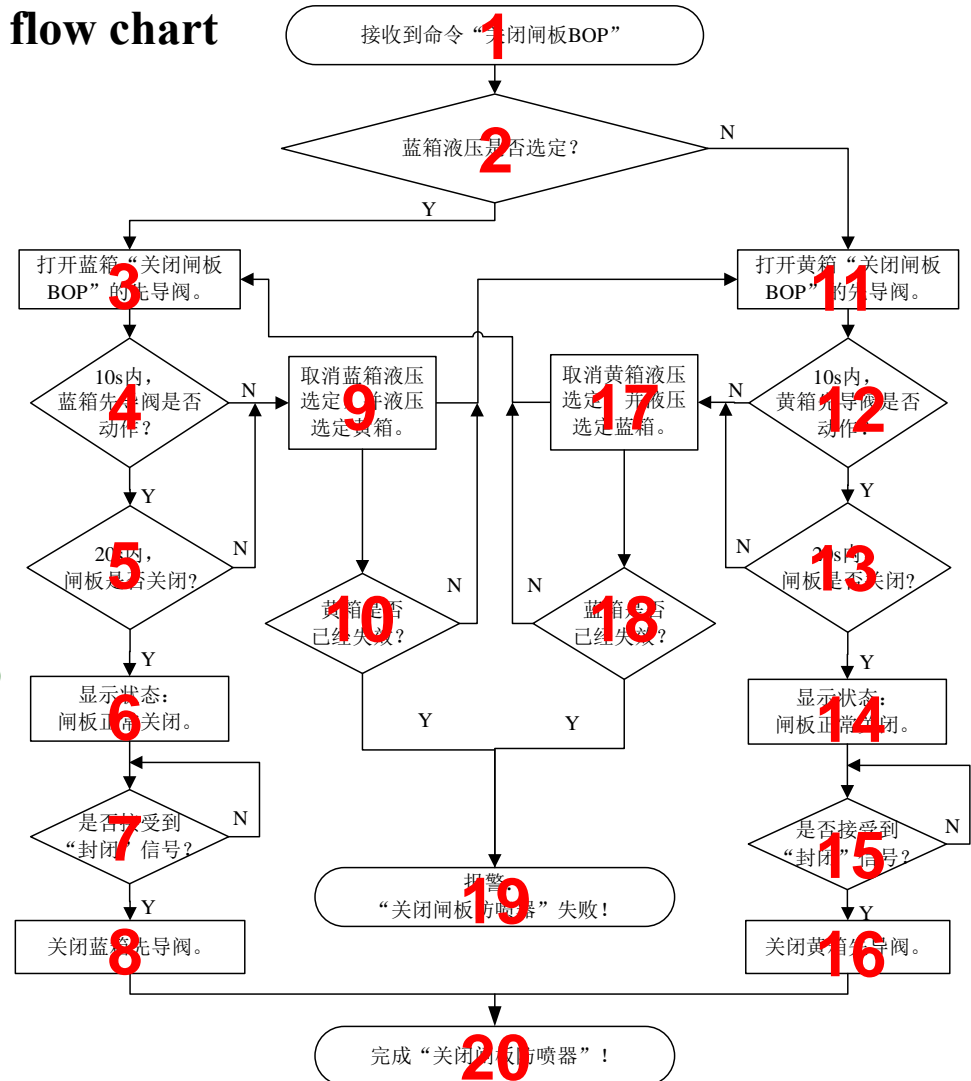


1. Subsea systems



“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”!





1. Subsea systems



Subsea BOP Control System

Welcome, ADMINISTRATOR
Login Logout

BOP Stack Pod Fluid Riser Conduit EDS Trend Alarm Readback Event

BOP Stack

- BOP Stack
- Upper Annual
- LMRP Connector
- Lower Annual
- Blind Shear Ram
- Casing Shear Ram
- Pipe Ram 1
- Pipe Ram 2
- Pipe Ram 3
- SSTV Ram
- Wellhead Connector

Mud Boost Valve: OPEN | BLOCK | CLOSE (0.0000)

Choke & Kill Stab: BLOCK | RETRACT

Pressure: 0.0000

Temperature: 0.0000

Upper Annular: OPEN | BLOCK | CLOSE (0.0000)

Inner Bleed Valve: OPEN | BLOCK | CLOSE (0.0000)

Outer Bleed Valve: OPEN | BLOCK | CLOSE (0.0000)

Stack Accumulator Pressure: 0.0000

LMRP Connector: OPEN | BLOCK | CLOSE (0.0000)

Secondary: UNLOCK | LOCK

Lower Annular: OPEN | BLOCK | CLOSE (0.0000)

Riser Record: ARMED | RESET

Riser Record Signal: RESET

Blind Shear Ram: OPEN | BLOCK | CLOSE (0.0000)

Upper Inner Choke: OPEN | BLOCK | CLOSE (0.0000)

Upper Outer Choke: OPEN | BLOCK | CLOSE (0.0000)

Casing Shear Ram: OPEN | BLOCK | CLOSE (0.0000)

Upper Inner Kill: OPEN | BLOCK | CLOSE (0.0000)

Upper Outer Kill: OPEN | BLOCK | CLOSE (0.0000)

Pipe Ram: OPEN | BLOCK | CLOSE (0.0000)

Pipe Ram: OPEN | BLOCK | CLOSE (0.0000)

Lower Inner Choke: OPEN | BLOCK | CLOSE (0.0000)

Lower Outer Choke: OPEN | BLOCK | CLOSE (0.0000)

Pipe Ram: OPEN | BLOCK | CLOSE (0.0000)

SSTV Ram: OPEN | BLOCK | CLOSE (0.0000)

Wellhead Connector: OPEN | BLOCK | CLOSE (0.0000)

Secondary: UNLOCK | LOCK

Pressure: 0.0000

Temperature: 0.0000

Alarm: Active Alarm

Blue Pod Flowmeter: 0.0000

Yellow Pod Flowmeter: 0.0000

Surface Flowmeter: 201.1254

Emergency Disconnect Sequence: PRELIMINARY | FINAL

Gasket Release: LOCK | BLOCK | RELEASE

MAIN EXIT

Subsea BOP stacks main control screen

Subsea BOP Control System

Welcome, ADMINISTRATOR
Login Logout

BOP Stack Pod Fluid Riser Conduit EDS Trend Alarm Readback Event

BOP Alarm

- BOP Alarm
- PLC Status
- GMR Status
- Histro Alarm

PLC A

PS CPU BTM ETH GBC1 GBC2 GBC3 GBC4

PLC B

PS CPU BTM ETH GBC1 GBC2 GBC3 GBC4

PLC C

PS CPU BTM ETH GBC1 GBC2 GBC3 GBC4

PLC A Power Off or Shutdown!

POWER-A1 POWER-A2

SBA	BUS 1A	BUS 1B	BUS 1C
1	GB01-D01	GB02-D01	GB03-D01
2	GB04-D02	GB05-D02	GB06-D01
3	GB07-D02	GB08-D03	GB09-D02
4	GB10-D03	GB11-D03	GB12-D03
5	GB13-D04	GB14-D04	GB15-D04
6	GB16-D05	GB17-D05	GB18-D04
7	GB19-D05	GB20-D06	GB21-D05
8	GB22-D06	GB23-D06	GB24-D06
9	GB25-D07	GB26-D07	GB27-D07
10	GB28-D08	GB29-D08	GB30-D07
11	GB31-D08	GB32-D01	GB33-D08
12	GB34-D11	GB35-D0	GB36-D11
13	GB37-D12	GB38-D3	GB39-D12
14	GB40-D13	GB41-A11	GB42-D3
15	GB43-A11	GB44-A2	GB45-A11
16	GB46-A2	GB47-A3	GB48-A2
17	GB49-A3	GB50-A3	

POWER-A1 POWER-A2

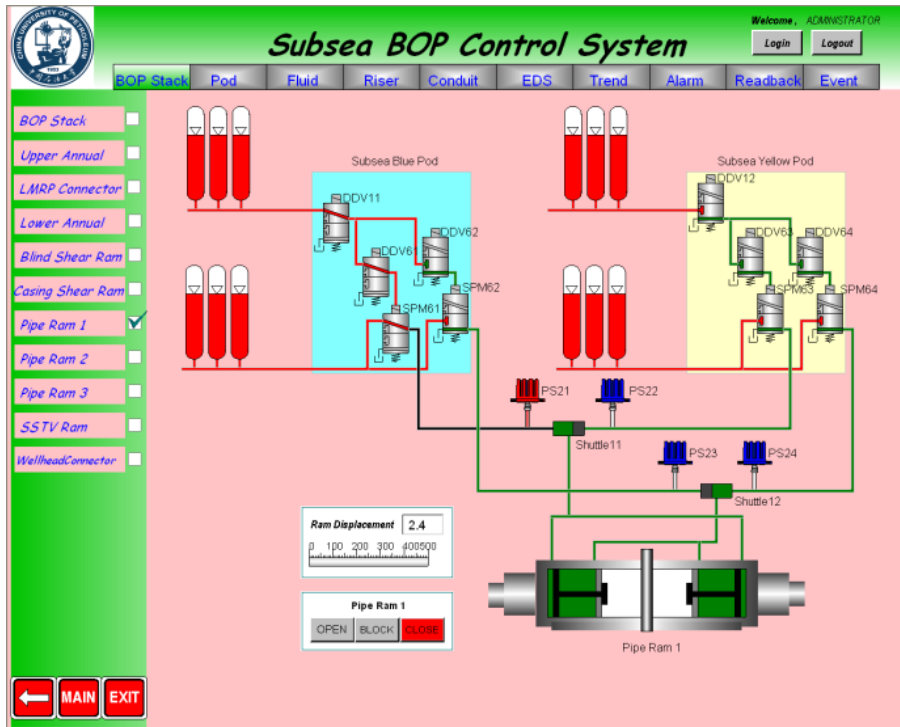
SBA	BUS 2A	BUS 2B	BUS 2C
1	GB51-D08	GB52-D09	GB53-D08
2	GB54-D010	GB55-D010	GB56-D08
3	GB57-D010	GB58-D011	GB59-D010
4	GB60-D011	GB61-D011	GB62-D011
5	GB63-D012	GB64-D012	GB65-D012
6	GB66-D013	GB67-D013	GB68-D012
7	GB69-D013	GB70-D014	GB71-D013
8	GB72-D014	GB73-D014	GB74-D014
9	GB75-D015	GB76-D015	GB77-D015
10	GB78-D016	GB79-D016	GB80-D015
11	GB81-D016	GB82-D04	GB83-D016
12	GB84-D14	GB85-D5	GB86-D14
13	GB87-D16	GB88-D16	GB89-D16
14	GB90-D16	GB91-A4	GB92-D16
15	GB93-A4	GB94-A5	GB95-A4
16	GB96-A5	GB97-A6	GB98-A5
17	GB99-A6	GB100-A6	

MAIN EXIT

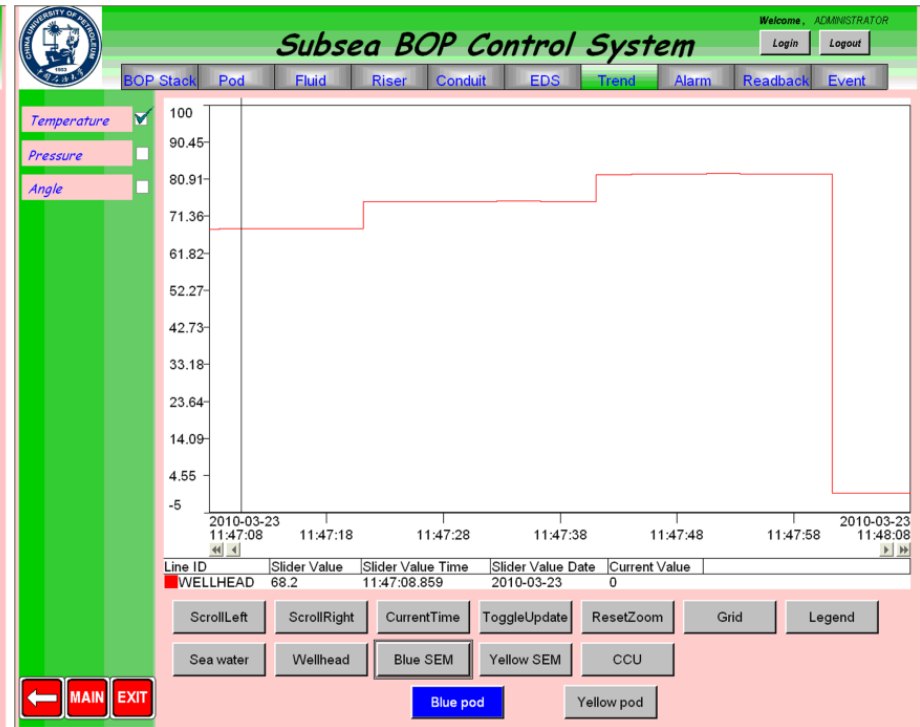
PLC screen



1. Subsea systems



Pipe ram control screen



Data screen



1. Subsea systems



http://caibaoping:1024/CiaWeb/index.html - Microsoft Internet Explorer

Welcome, ADMINISTRATOR
Subsea BOP Control System Login Logout

BOP Stack Pod Fluid Riser Conduit EDS Trend Alarm Readback Event

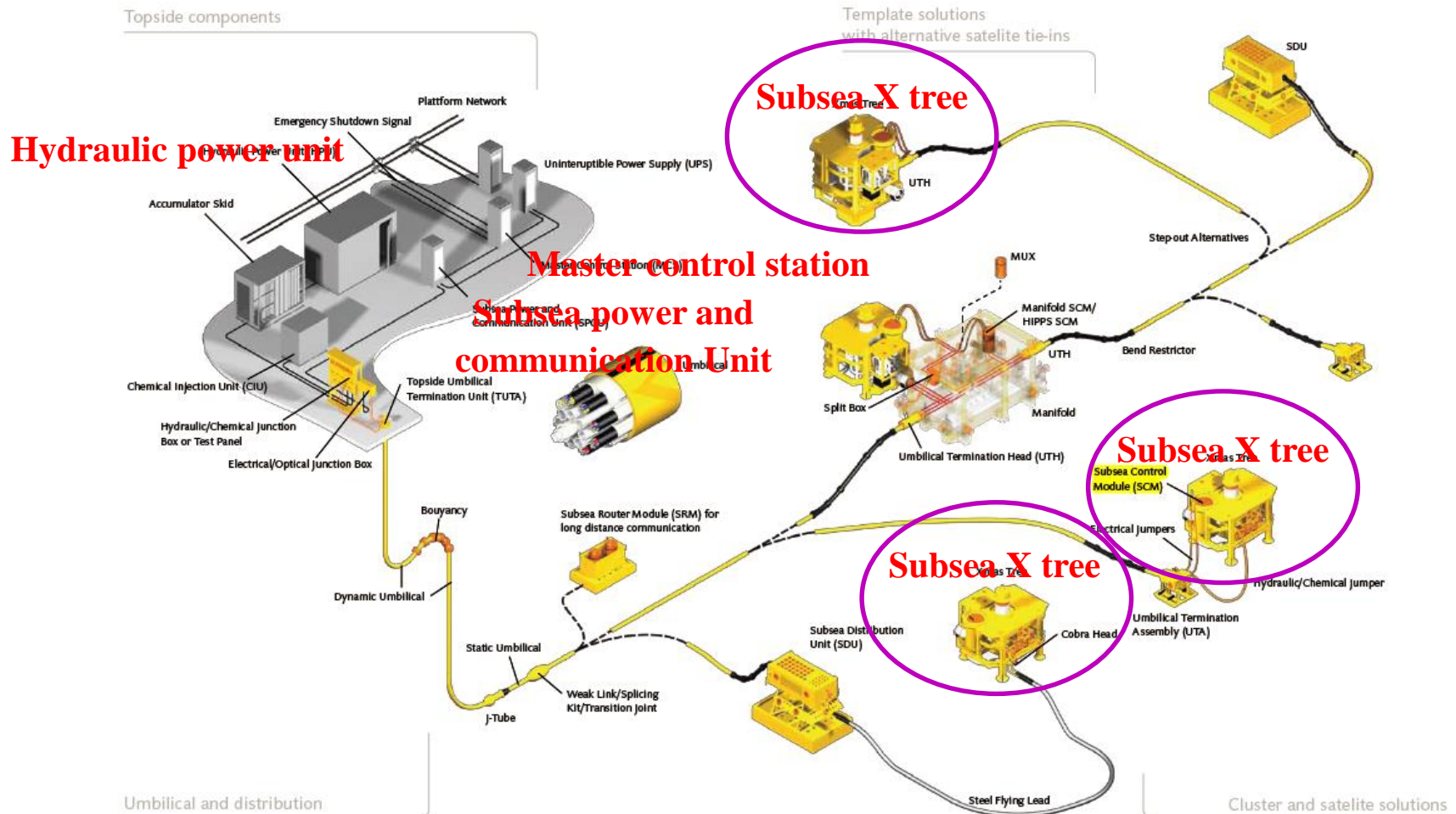
Project Name	Alarm ID	Date	Time	State	Ack	Message
BOP_PROTOTYPE3	SENSOR3	三月	2311:48	ALARM	N	Temperature sensor 3 is failed.
BOP_PROTOTYPE3	SENSOR2	三月	2311:47	ALARM	N	Temperature sensor 2 is failed.
BOP_PROTOTYPE3	SENSOR1	三月	2311:47	ALARM	N	Temperature sensor 1 is failed.
BOP_PROTOTYPE3	PS21	三月	2311:35	ALARM	N	PS21 can't detect the hydraulic pressure signal of closing pipe ram
BOP_PROTOTYPE3	PLCB	三月	2311:30	ALARM	N	PLCB power off
BOP_PROTOTYPE3	PLCA	三月	2311:27	ALARM	N	PLCA power off
BOP_PROTOTYPE3	\$EVICE DOWN	三月	2311:18	ALARM	Y	Comm error or dynamic disable, device: CAIBAOPING - PLC C

7 Mar 23 11:48
Ack Reset Delete Ack and Reset Ack First Ack All
Toggle Setup Refresh Help View Stack Comments

MAIN EXIT Switch

Remote monitoring alarm screen

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 field in South China Sea



1. Subsea systems



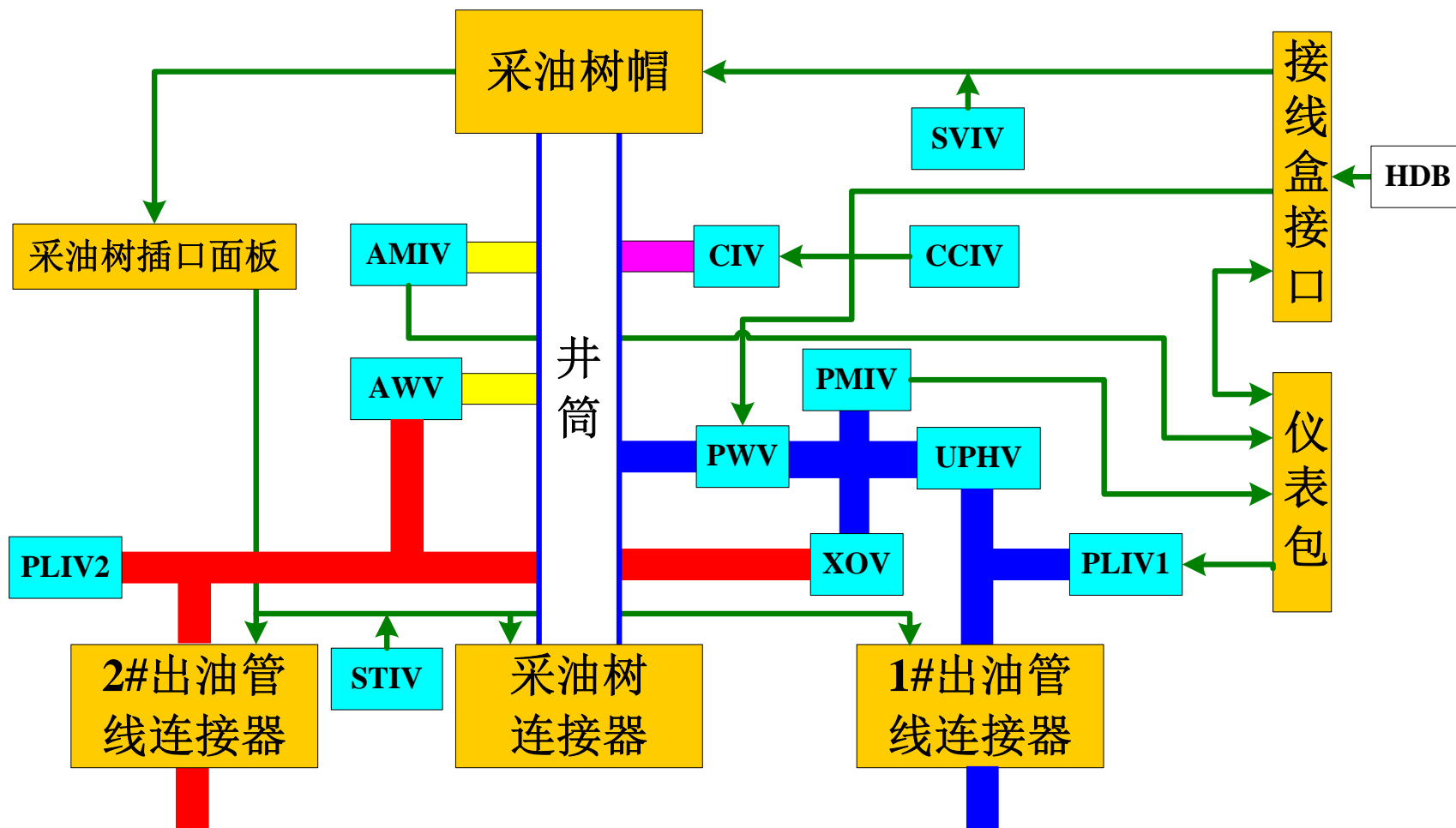
1.3. Subsea X tree test system



Subsea hydraulic tree in Liuhua 11-1 oil



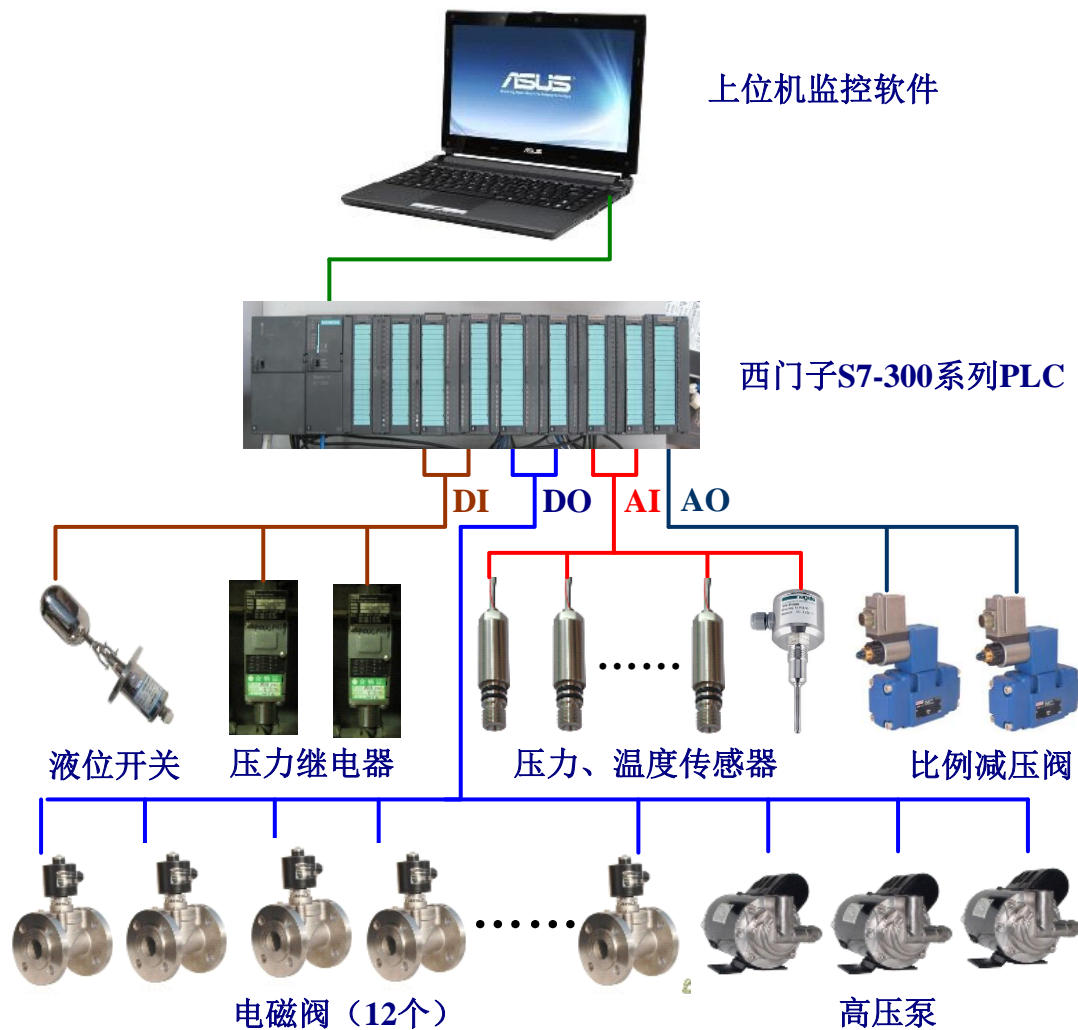
1. Subsea systems



Schematic diagram of the subsea X tree



1. Subsea systems



Control system of the subsea X tree test platform



1. Subsea systems



水下控制系统地面测试单元

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首页 测试工具 出油管路测试 采油树液压测试 密封轴套测试 油管挂测试 联合测试 压力曲线 报警记录

生产出油管路测试 环空出油管路测试 交叉出油管路测试 水泵停止

压力示数 0 psi 水泵启动

步骤一 生产出油管路测试

将4 1/16" -5k盲法兰和BX-155环形垫圈安装在生产出油管路上;

步骤二

初步测试: 压力为3400psi, 保压时间为3分钟
测试单元#1管线与生产出油管路相连, 打开截止阀, 水泵压力设定为3400psi, 点击水泵启动按钮;
压力示数为3400psi后, 关闭截止阀, 点击水泵停止按钮;
3分钟后, 打开截止阀, 调节球阀泄压;

步骤三

初步测试: 压力为3400psi, 保压时间为15分钟
测试单元#1管线与生产出油管路相连, 打开截止阀, 水泵压力设定为3400psi, 点击水泵启动按钮;
压力示数为3400psi后, 关闭截止阀, 点击水泵停止按钮;
15分钟后, 打开截止阀, 调节球阀泄压;

退出运行系统

水下控制系统地面测试单元

2014-7-9 14:59:16

首页 测试工具 出油管路测试 采油树液压测试 密封轴套测试 油管挂测试 联合测试 压力曲线 报警记录

液管管线测试 压力设定 0 psi 保压时间设定 0 min

#3管线 #4管线 #5A管线 #5B管线 #8A管线 #19管线 #20管线 #7管线 #24管线 #30管线 #32管线

#4管线 #6A管线 #6B管线 #13管线 #21管线 #23管线 #31管线 #34管线

#8管线 #9管线 #10管线 #11管线 #12管线

加压 保压 泄压 停止

psi #11管线 #12管线

压力显示面板

步骤一

测试单元#11或#12管线与采油树#4管线相连, 点击泄压按钮;
压力设定为250psi, 保压时间设定为3分钟, 测试单元#8 (#9或#10) 管线与采油树#3管线相连, 点击加压按钮, 压力示数为250psi后, 点击保压按钮;
压力示数为0后, 点击停止按钮;

步骤二

压力设定为4500psi, 保压时间设定为3分钟; 测试单元#8 (#9或#10) 管线与采油树#3管线相连, 点击加压按钮, 压力示数为4500psi后, 点击保压按钮;
压力示数为0后, 点击停止按钮;

步骤三 (此步骤重复3次)

压力设定为3000psi;
测试单元#11或#12管线与采油树#3管线相连, 点击加压按钮;
压力示数为3000psi后, 点击泄压按钮;

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退出运行系统

Screen of the subsea X tree test system



1. Subsea systems



水下控制系统地面测试单元 2014-7-9 15:01:39

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采油树安装功能测试

步骤一 (送入工具锁紧到密封轴套功能测试)

按照采油树液压测试步骤进行采油树液压测试:

步骤二 (准备)

安装仪表包, 将采油树蓄能器氮气压力设定为 650psi:
按照下表调整所有采油树阀门的位置:

采油树阀门位置	
阀名称	位置
环空检测隔离阀 (AMIV)	开
环空翼阀 (AWV)	开
补修回路隔离阀 (CCIV)	关
化学药剂注入阀 (CIV)	关
生产检测隔离阀 (PMIV)	开
生产翼阀 (PWV)	关
上部生产管汇阀 (UPHV)	开
转换阀 (XOV)	开
安全阀隔离阀 (SVIV)	开
安全检测隔离阀 (STIV)	开
#1管线隔离阀 (PLIV1) *	开
#2管线隔离阀 (PLIV2) *	开

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泵控制面板

#1泵	#2泵	#3泵	#2管线
启动	启动	启动	加压 保压
停止	停止	停止	泄压 停止

1# 压力设定 0 psi 保压时间设定 0 min

#3管线	#4管线	#5管线	#6管线	#7管线
加压 泄压	加压 泄压	加压 保压	加压 保压	加压 保压
泄压 停止	泄压 停止	泄压 停止	泄压 停止	泄压 停止

2# 压力设定 0 psi 保压时间设定 0 min

#8管线	#9管线	#10管线	#11管线	#12管线
加压 保压	加压 保压	加压 保压	加压 泄压	加压 泄压
泄压 停止	泄压 停止	泄压 停止	泄压 停止	泄压 停止

压力显示面板

压	#1管线	0	psi	#7管线	0	psi
力	#2管线	0	psi	#8管线	0	psi
显	#3管线	0	psi	#9管线	0	psi
示	#4管线	0	psi	#10管线	0	psi
面	#5管线	0	psi	#11管线	0	psi
板	#6管线	0	psi	#12管线	0	psi

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水下控制系统地面测试单元 2014-7-9 15:12:17

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管体压力显示

管体压力显示

时间	#1管体压力	#2管体压力	#3管体压力	#4管体压力	#5管体压力	#6管体压力	#7管体压力	#8管体压力
4 2014-7-9 15:11:44.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5 2014-7-9 15:11:46.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6 2014-7-9 15:11:48.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7 2014-7-9 15:11:50.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
8 2014-7-9 15:11:52.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
9 2014-7-9 15:11:54.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
10 2014-7-9 15:11:56.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
11 2014-7-9 15:11:58.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
12 2014-7-9 15:12:00.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
13 2014-7-9 15:12:02.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
14 2014-7-9 15:12:04.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
15 2014-7-9 15:12:06.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
16 2014-7-9 15:12:08.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
17 2014-7-9 15:12:10.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
18 2014-7-9 15:12:12.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
19 2014-7-9 15:12:14.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
20 2014-7-9 15:12:16.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

[退出运行系统](#)

压力显示面板

#1管线 0.00 psi

#2管线 0.00 psi

#3管线 0.00 psi

#4管线 0.00 psi

#5管线 0.00 psi

#6管线 0.00 psi

#7管线 0.00 psi

#8管线 0.00 psi

#9管线 0.00 psi

#10管线 0.00 psi

#11管线 0.00 psi

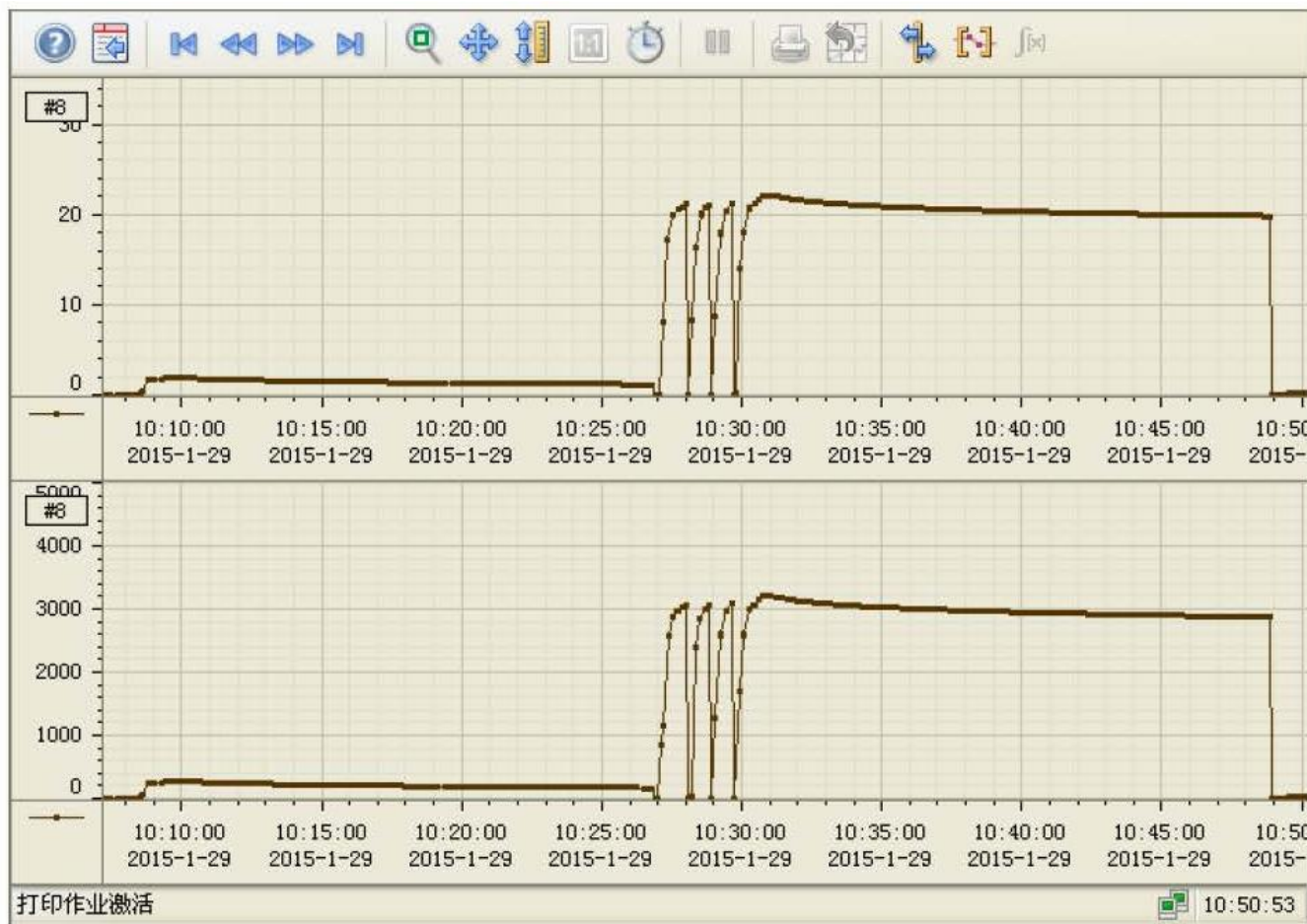
#12管线 0.00 psi

[退出运行系统](#)

Screen of the subsea X tree test system



1. Subsea systems



Detected pressure trend for a certain pipeline



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 - **2. Reliability methodology**
 - **3. Fault diagnosis methodology**



2. Reliability methodology



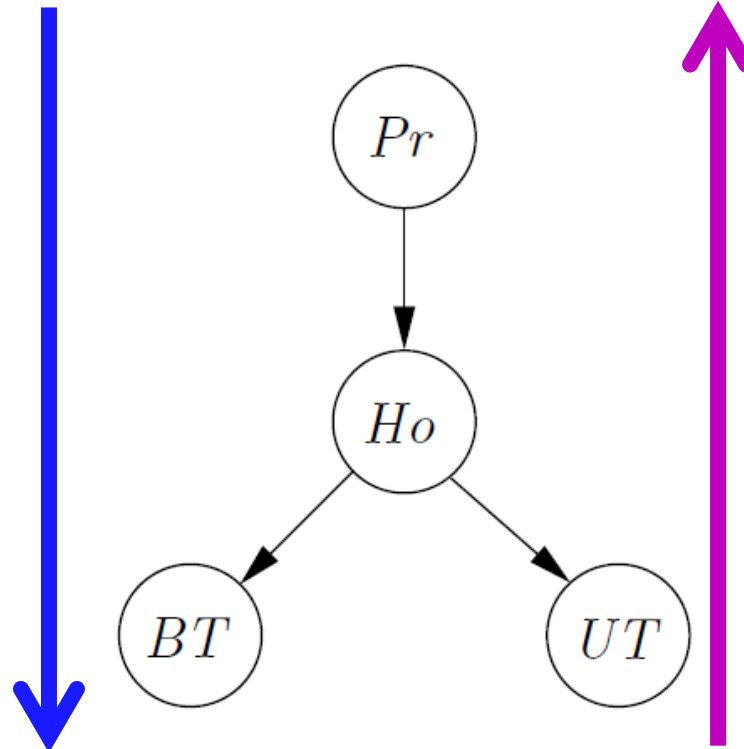
What can BNs do?

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

**Forward:
Predictive**

Such as:

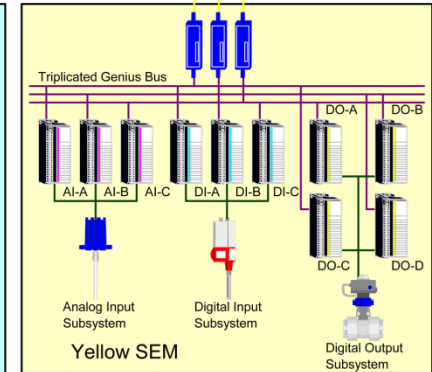
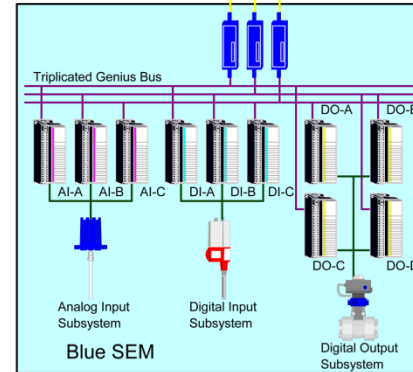
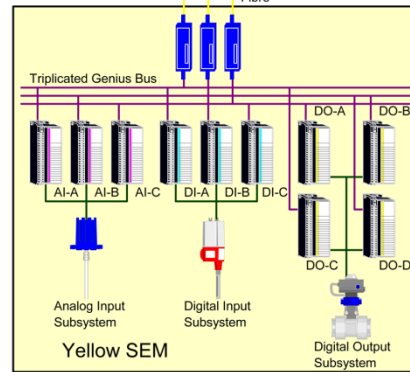
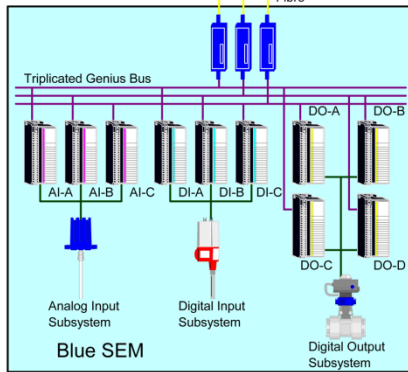
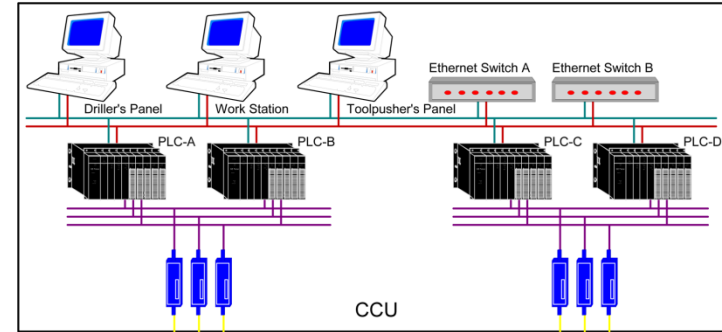
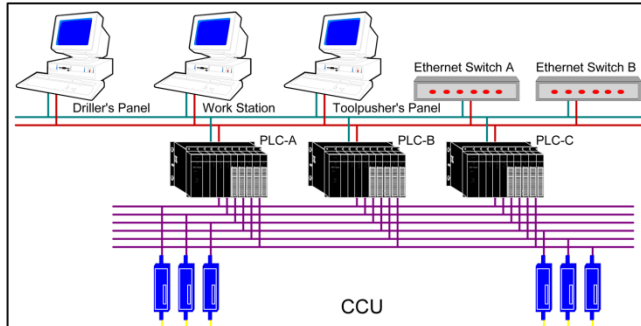
- **Reliability**
- **Risk**
- **Safety**



**Backward:
Diagnostic**

Such as:

- **Fault diagnosis**
- **Disease diagnosis**

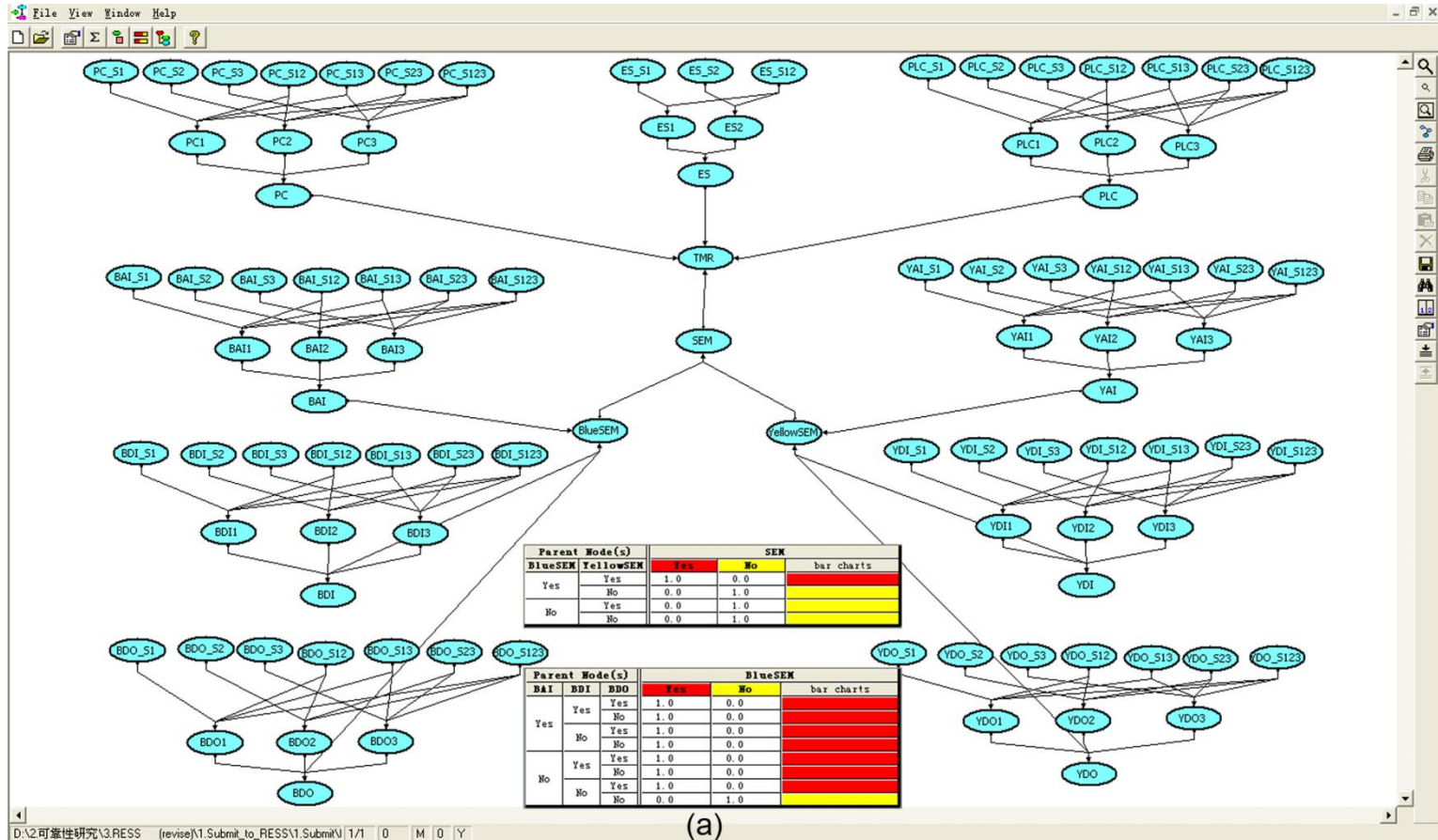


(a)

(b)

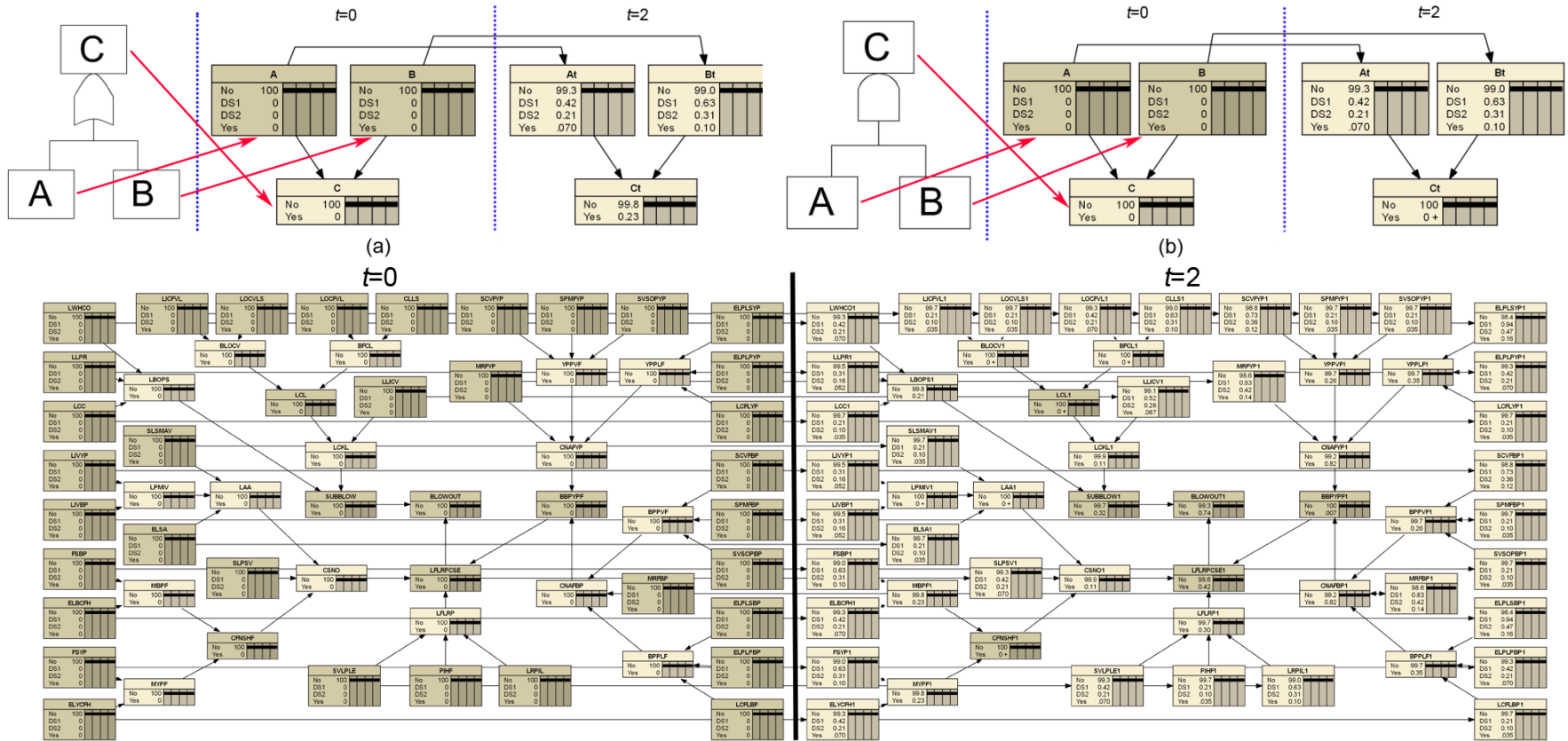
Configurations of Triple Modular Redundancy (TMR) and Double Dual Modular Redundancy (DDMR) control systems for subsea BOP

2. Reliability methodology



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).

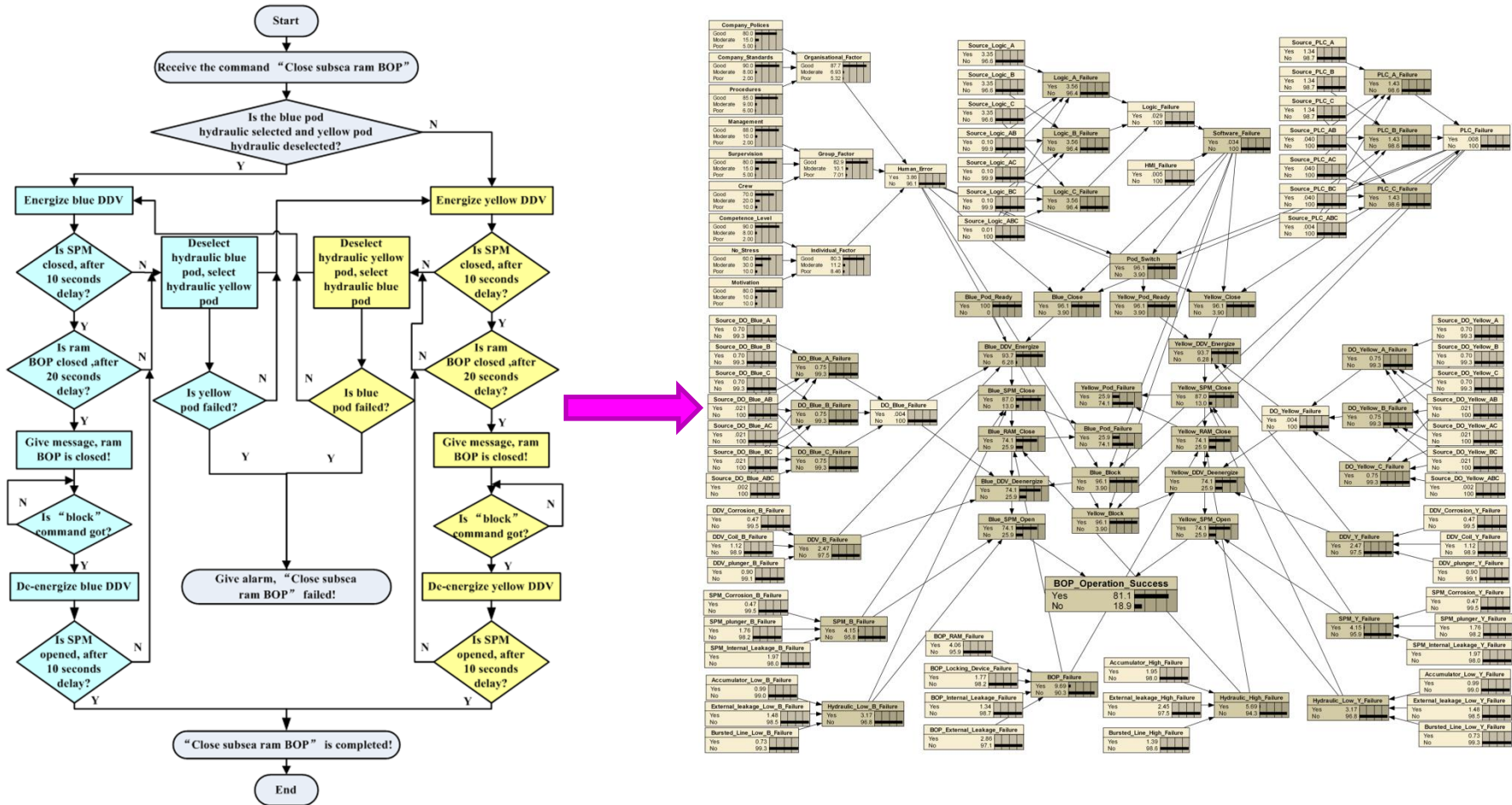
2. Reliability methodology



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

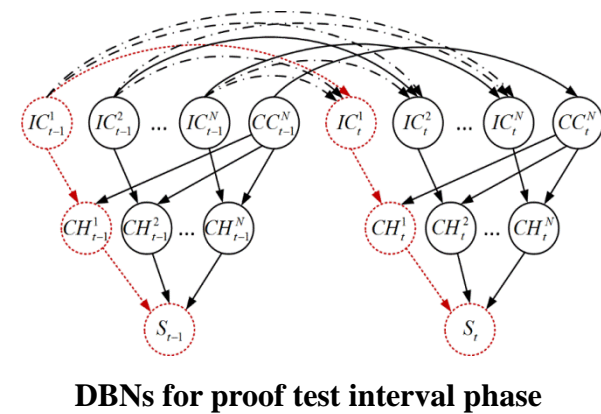
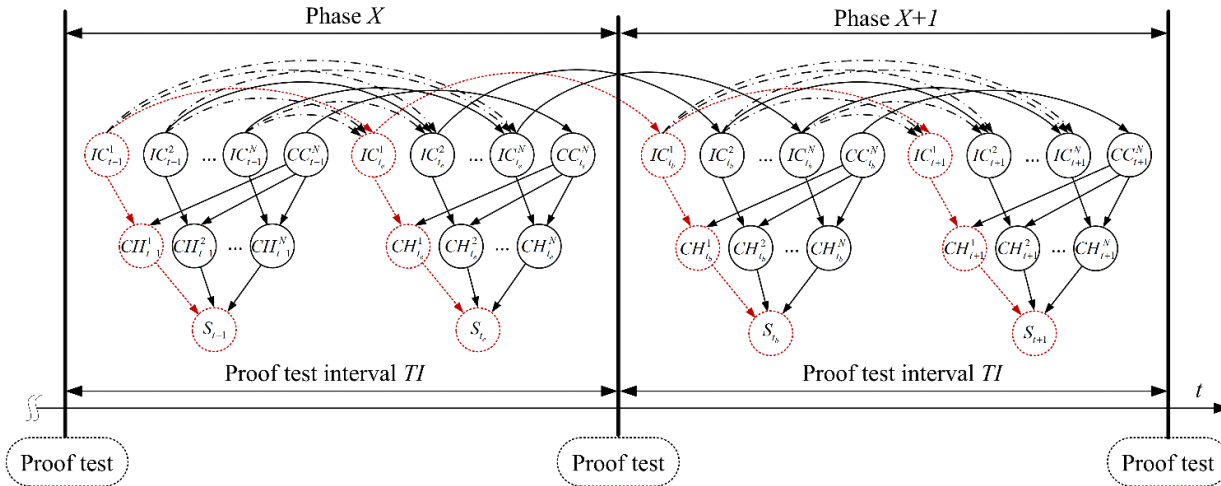


2. Reliability methodology

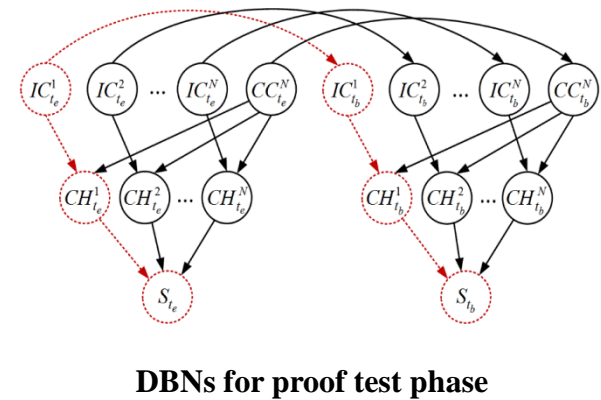
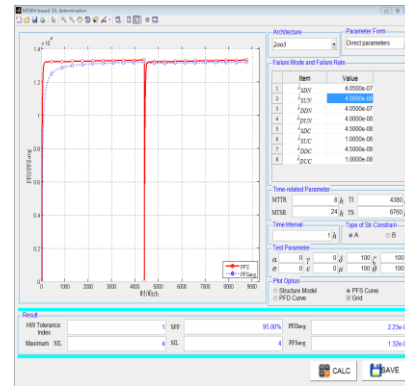
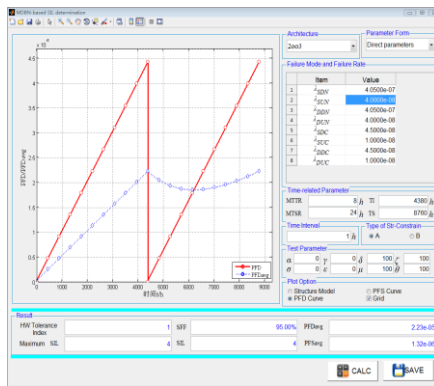


Application of Bayesian Networks in Quantitative Risk Assessment of Subsea Blowout Preventer Operations (Cai, RA, 2013)

2. Reliability methodology



Schematic diagram of MDBNs for SIL determination



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



2. Reliability methodology



Reliability Modeling and Evaluation of Subsea Blowout Preventer Systems

Yonghong Liu
Baoping Cai
Renjie Ji
Zengkai Liu
Yanzhen Zhang

 科学出版社



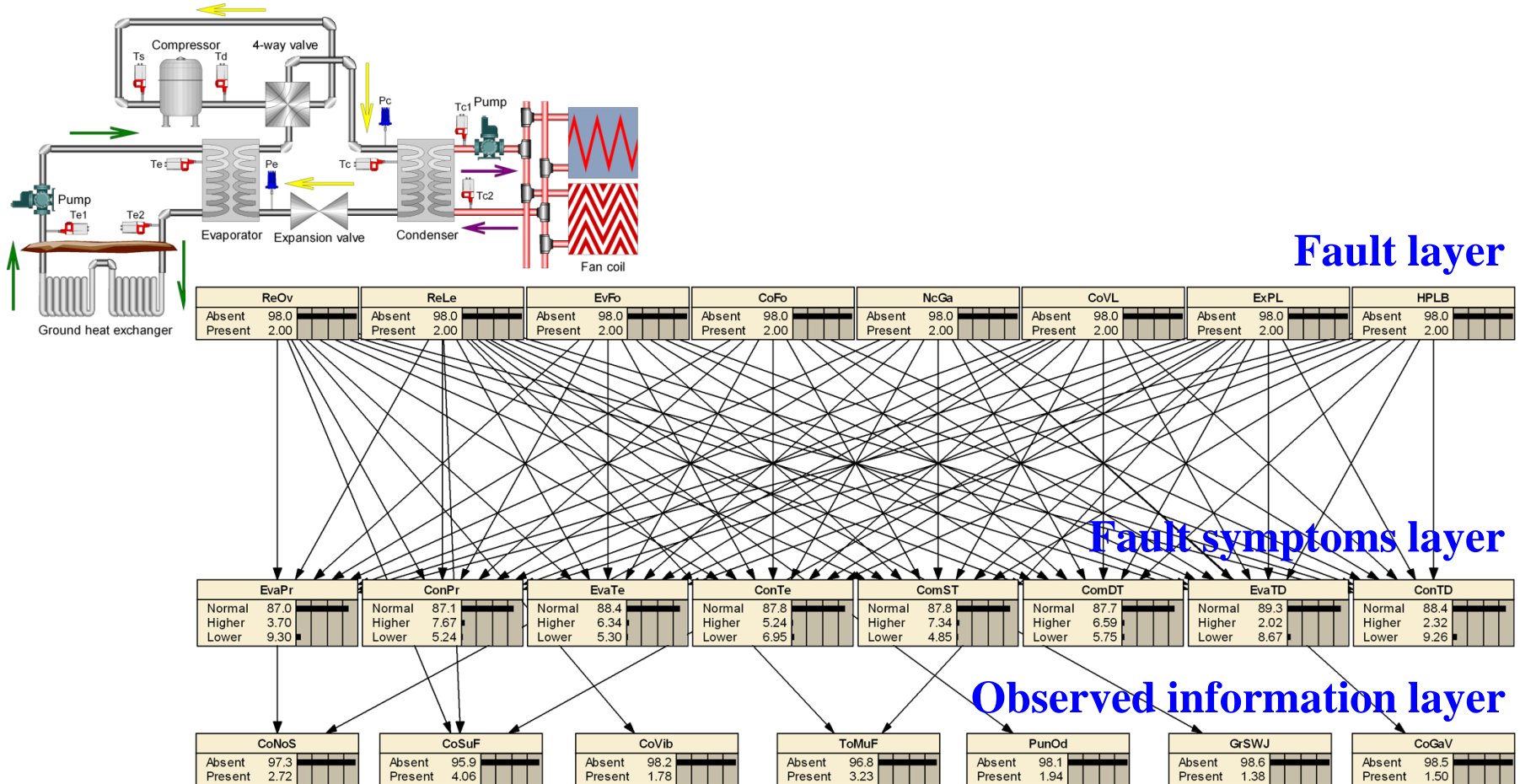
Contents



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

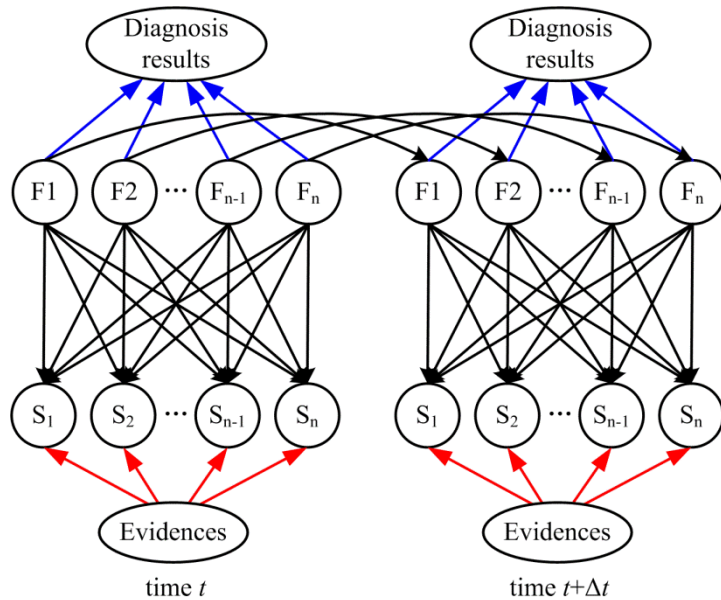


2. Procedures of FD with BNs CityU



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

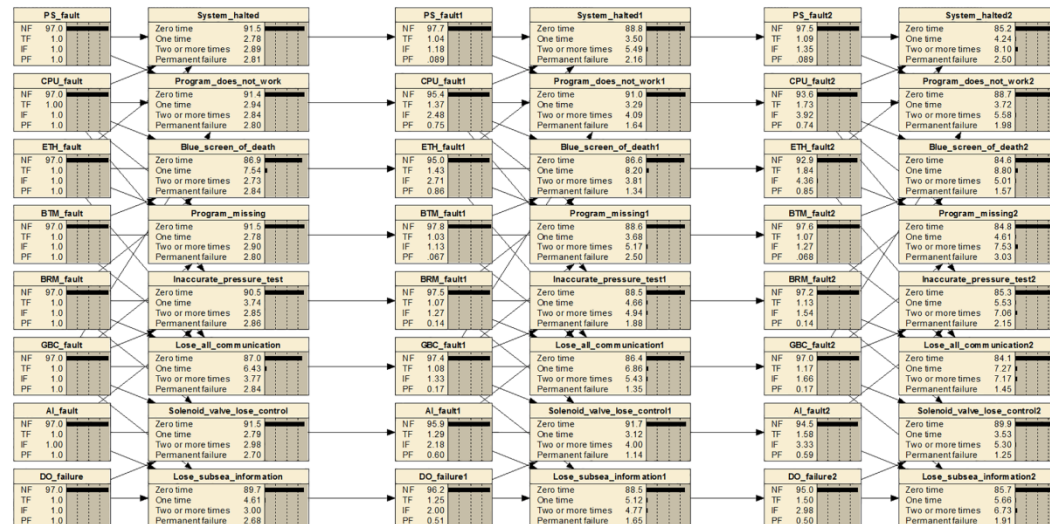
3.2. DBNs for fault diagnosis



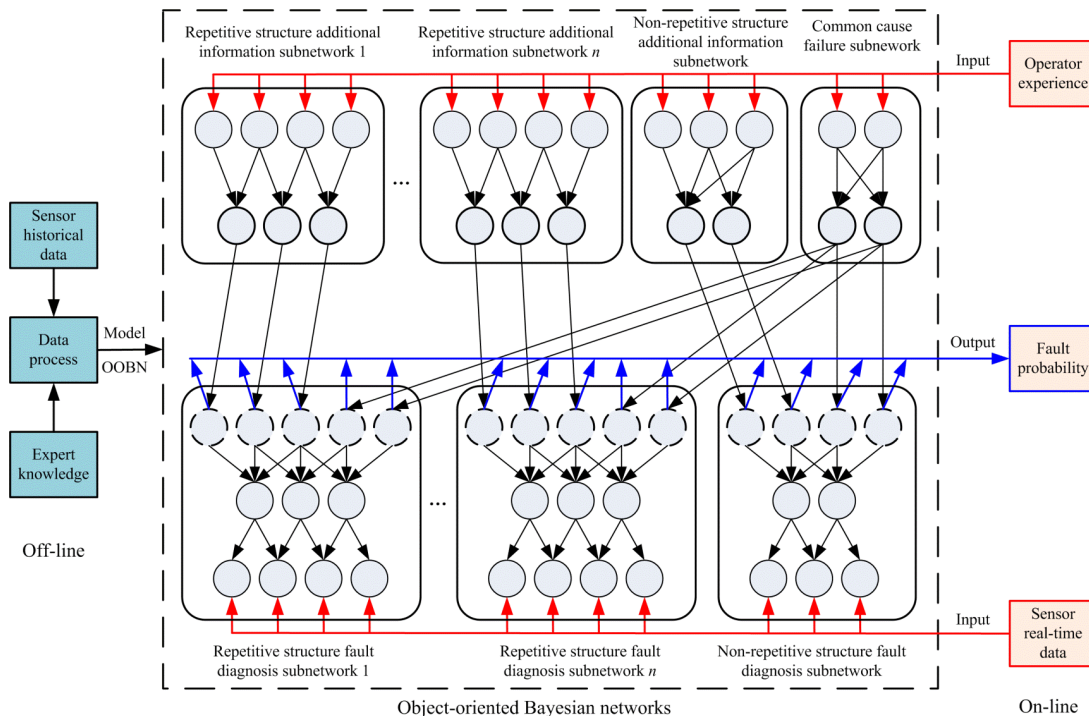
Given same fault symptoms, the diagnostic result may be totally different in different time periods because of the performance degradation of components.

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.

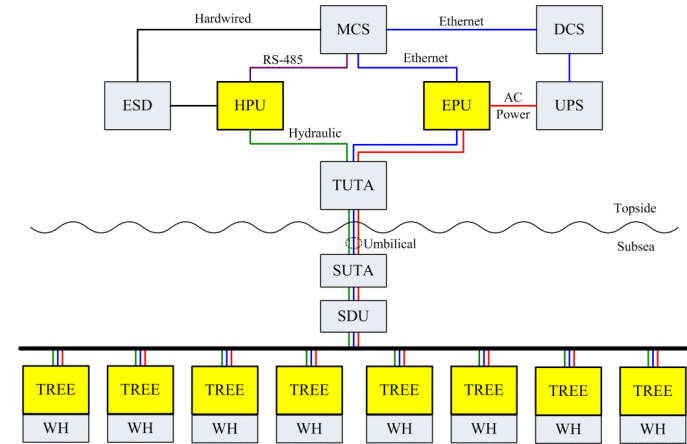
DBN-based fault diagnosis model for GMR control systems (Cai, TASE, 2016)



3.3. OOBNs for fault diagnosis



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

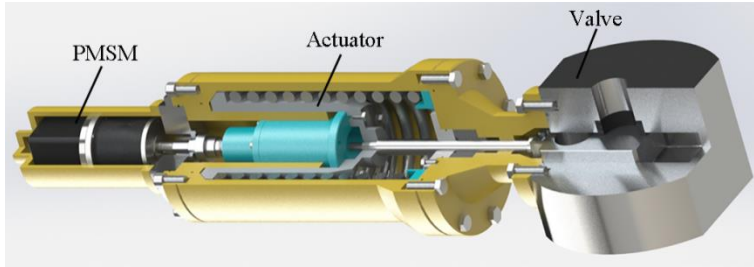


OOBNs have the following advantages:

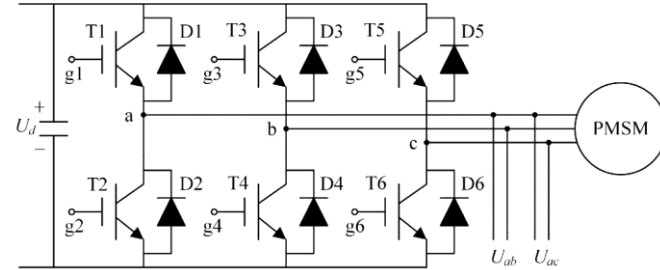
- (1) supports top-down model construction process;
- (2) are constructed by integrating small and understandable network fragments, benefiting knowledge acquisition and communication between modelers and domain experts;
- (3) reduces the complexity of building BNs, and improves the reusability of models;
- (4) have high average rate of convergence and time efficiency thanks to the characteristic of encapsulation and hierarchy.



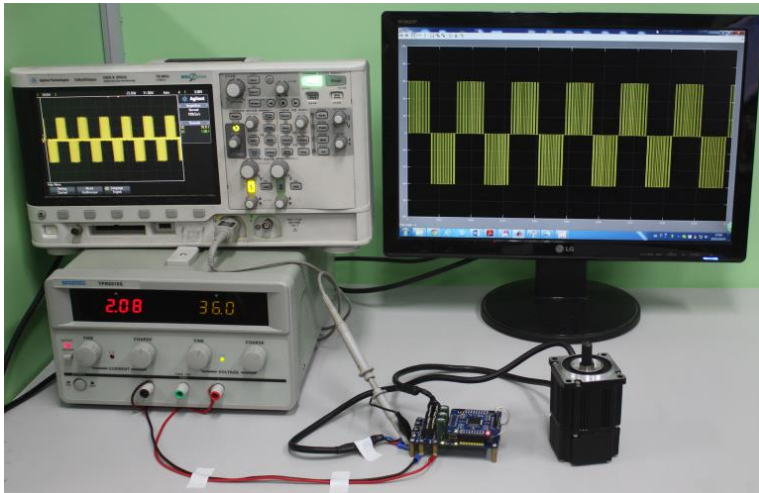
2. Procedures of FD with BNs CityU



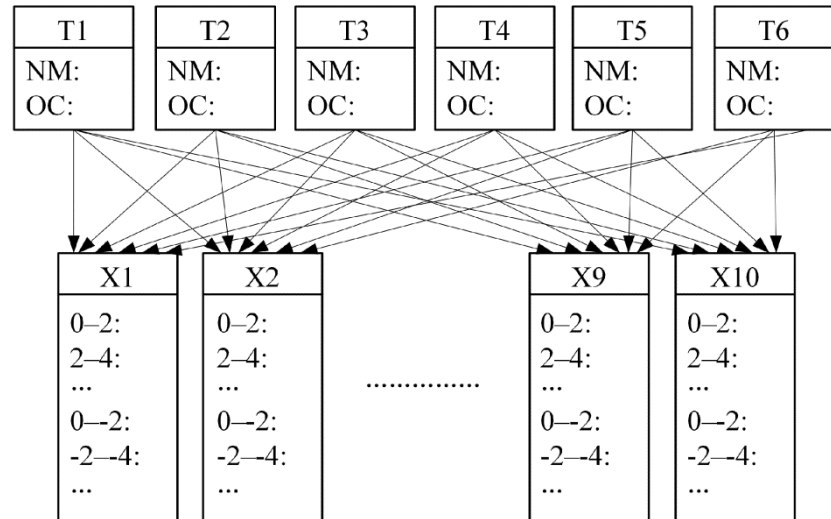
Subsea electric actuator



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

华北荣盛 深水防喷器故障诊断系统

05/15/2014 10:26:20

测试日期: 1 2

压力:

功能:

ROV:

EDS:

紧急系统:

- EDS
- 自动剪切

系统状态:

- 电控系统
- 光纤通信
- 电力
- 连接器
- 事件登录数据

状态说明: 正常 (绿), 故障 (红)

位置符号: 开启 (黄), 关闭 (黑)

华北荣盛 深水防喷器故障诊断系统

05/15/2014 10:27:36

上BOP控制

下BOP控制

BOP检修

蓄能器充压

状态说明: 正常 (白), 过高 (红), 过低 (绿)

诊断结果	发生概率
1. 蓝箱蓄能器1发生泄露	0.000
2. 蓝箱蓄能器2发生泄露	0.000
3. 蓝箱电磁阀1不能动作	0.000
4. 蓝箱电磁阀2不能动作	0.000
5. 黄箱蓄能器5泄露	0.000
6. 黄箱蓄能器6泄露	0.000
7. 黄箱电磁阀5不能动作	0.000
8. 黄箱电磁阀6不能动作	0.000
9. 梭阀1不能动作	0.000
10. 梭阀2不能动作	0.000
11. 上防喷器闸板卡住	0.000

华北荣盛 深水防喷器故障诊断系统

05/15/2014 10:28:38

上BOP控制

下BOP控制

BOP检修

蓄能器充压

状态说明: 正常 (白), 过高 (红), 过低 (绿)

诊断结果	发生概率
1. 蓝箱蓄能器9发生泄露	0.000
2. 蓝箱蓄能器10发生泄露	0.000
3. 蓝箱电磁阀9不能动作	0.000
4. 蓝箱电磁阀10不能动作	0.000
5. 黄箱蓄能器13发生泄露	0.000
6. 黄箱蓄能器14发生泄露	0.000
7. 黄箱电磁阀13能动作	0.000
8. 黄箱电磁阀14能动作	0.000
9. 梭阀6不能动作	0.000
10. 梭阀6不能动作	0.000
11. 上防喷器闸板卡住	0.000

诊断结果	发生概率
1. 蓄能器11发生泄露	0.000
2. 蓄能器12发生泄露	0.000
3. 电磁阀11不能动作	0.000
4. 电磁阀12不能动作	0.000
5. 黄箱蓄能器15发生泄露	0.000
6. 黄箱蓄能器16发生泄露	0.000
7. 黄箱电磁阀15能动作	0.000
8. 黄箱电磁阀16能动作	0.000
9. 梭阀7不能动作	0.000
10. 梭阀8不能动作	0.000
11. 下防喷器闸板卡住	0.000

华北荣盛 深水防喷器故障诊断系统

05/15/2014 10:29:14

Start Date-Time: 2014/5/14 星期三 10:29:11

End Date-Time: 2014/5/15 星期四 10:29:11

实时诊断

timestamp	point_id	ALRM	PREV	VAL	QUALT
2014/5/15 星期四	HYDR_DIA LOCK A	Normal		2.000000	
2014/5/15 星期四	HYDR_DIA LOCK A	Normal		2.000000	
2014/5/15 星期四	HYDR_DIA LOCK A	Normal		2.000000	
2014/5/15 星期四	HYDR_DIA LOCK A	Normal		2.000000	
2014/5/15 星期四	HYDR_DIA LOCK B	Normal		0.000000	
2014/5/15 星期四	HYDR_DIA LOCK B	Normal		0.000000	
2014/5/15 星期四	HYDR_DIA LOCK SH	Normal		2.000000	
2014/5/15 星期四	HYDR_DIA LOCK SH	Normal		2.000000	
2014/5/15 星期四	HYDR_DIA LOCK SH	Normal		2.000000	
2014/5/15 星期四	HYDR_DIA LOCK SH	Normal		2.000000	
2014/5/15 星期四	HYDR_DIA LOCK S	Normal		2.000000	
2014/5/15 星期四	HYDR_DIA LOCK S	Normal		2.000000	
2014/5/15 星期四	HYDR_DIA LOCK S	Normal		2.000000	
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2014/5/15 星期四	HYDR_DIA LOCK A	Normal		2.000000	
2014/5/15 星期四	HYDR_DIA LOCK A	Normal		2.000000	
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2014/5/15 星期四	HYDR_DIA LOCK A	Normal		2.000000	
2014/5/15 星期四	HYDR_DIA LOCK A	Normal		2.000000	
2014/5/15 星期四	HYDR_DIA LOCK A	Normal		2.000000	
2014/5/15 星期四	HYDR_DIA CTRL SO	Normal		2.000000	
2014/5/15 星期四	HYDR_DIA CTRL SO	Normal		2.000000	
2014/5/15 星期四	HYDR_DIA CTRL SO	Normal		2.000000	
2014/5/15 星期四	HYDR_DIA CTRL AC	Normal		2.000000	
2014/5/15 星期四	HYDR_DIA CTRL AC	Normal		2.000000	
2014/5/15 星期四	HYDR_DIA CTRL AC	Normal		0.000000	
2014/5/15 星期四	HYDR_DIA CTRL SH	Normal		2.000000	
2014/5/15 星期四	HYDR_DIA CTRL SH	Normal		2.000000	
2014/5/15 星期四	HYDR_DIA CTRL SH	Normal		2.000000	

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)



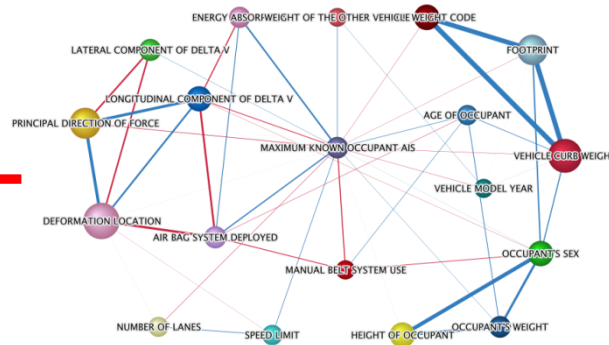
6. Future research directions



6.1. FD methodology integrated big data and BNs



+



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FD

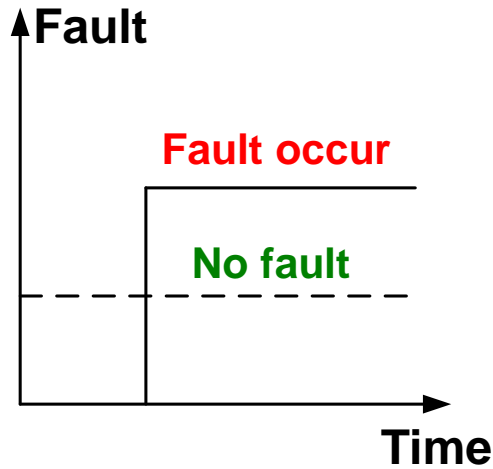
Two important parts:

- ✓ Fault feature extraction method from big data;
- ✓ BN-based fault diagnosis method using these fault features.

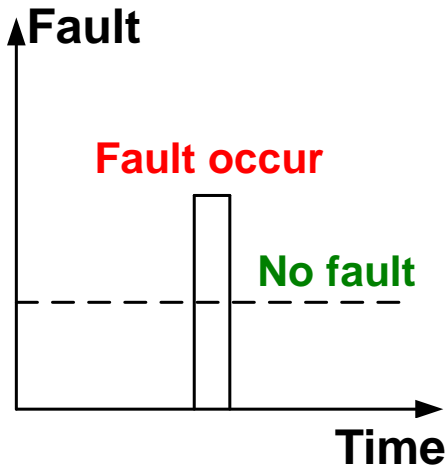


6. Future research directions

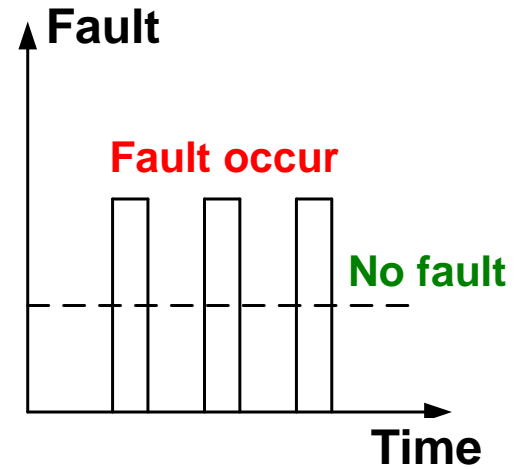
6.2. BN-based non-permanent FD



Permanent fault



Transient fault

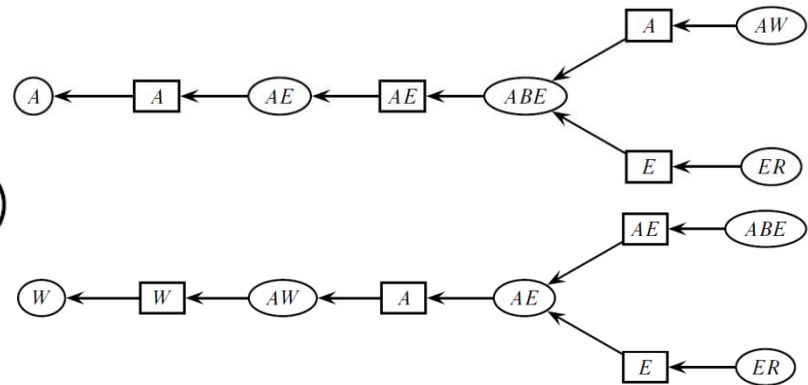
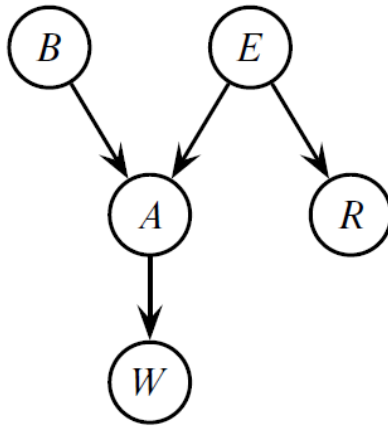


Intermittent fault

How to:

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

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



Traditional inference:

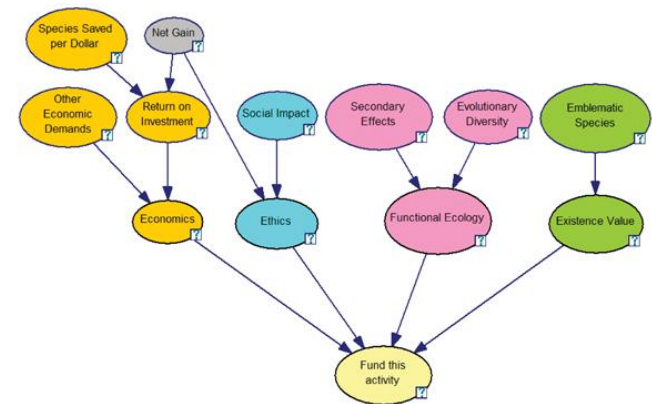
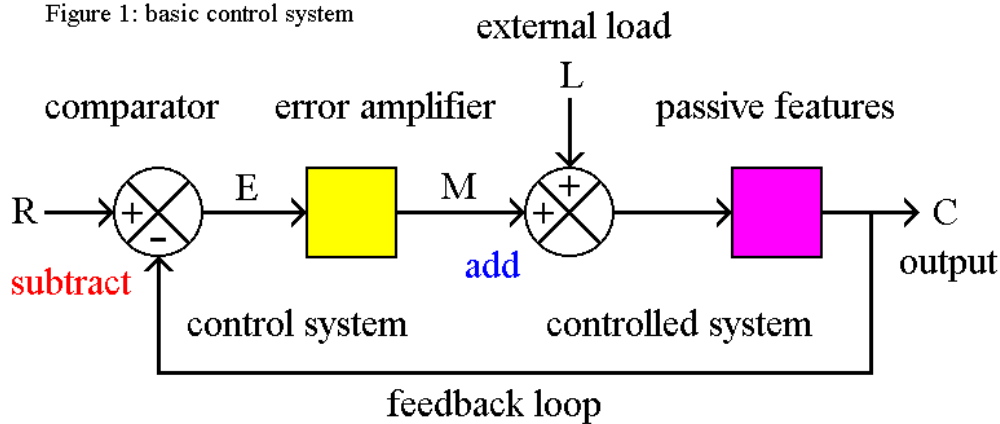
- Becomes increasingly expensive;
- Costs lots of time;
- Hardly perform real-time FD.

It is necessary to:

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

6.4. BNs for closed-loop control system FD

Figure 1: basic control system



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

A wide-angle photograph of a deep blue ocean stretching to the horizon under a bright blue sky with wispy white clouds. The text 'Thank you!' is centered in the upper half of the image.

Thank you!