Optimization of Subsea BOP Stack Control System Based on Underwater Acoustic Wireless Communication Network

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Abstract. In view of the advantages of low cost and fast communication in wireless communication technology, a new control system of subsea BOP stack based on underwater acoustic communication network is proposed for mechanical automation mining of subsea oil field. The system can realize wireless communication by using sound wave; the system increases a way of micro PLC in subsea control box to start the automatic shearing subsystem of oil well drilling pipe, and the subsystem has an automatic switching function of the two states of "forbidden" and "standby". Compared to the existing control system, the safety and reliability and automation degree of the new system are greatly improved; especially the safety of personnel and equipment in critical condition can further be ensured. Therefore the new system can provide important technical reference to develop subsea BOP stack control system in the sea.

Introduction

The subsea BOP stack is the key underwater well control equipment, which has played an important role in ensuring the safety of marine operation, the safety of personnel and equipment, and the protection of the marine environment. Currently, the key technology of subsea BOP stack control system is mastered by several well-known BOP manufacturers abroad, however the development of BOP control system for subsea oil well drilling is just in its infancy, especially its subsystem of automatic shearing drilling pipe has been seldom investigated [1].

As subsea oil well drilling is far from the shore and the operation conditions at sea are extremely poor, it is very difficult to deal with an emergency, escape and rescue. In the process of oil production, if the control system of the subsea BOP stack is out of order, it is highly possible to lead to catastrophic accidents [2]. Therefore, based on the research of the traditional BOP stack control system, this paper overcomes the shortcomings of the existing system such as the wired and poor working environment, a new BOP control system based on underwater acoustic wireless communication network is proposed. It is helpful to improve the information and automation degree of subsea BOP stack control system and reduce its costs.

Underwater Acoustic Communication Network

Underwater sensor network can be realized to many applications, such as oceanographic data collection, pollution control, offshore exploration, disaster prevention, tactical observation and navigation. However its key technology just is the network of underwater acoustic communication [3].

The Network of Underwater Acoustic Communication

The network of underwater acoustic communication is usually composed of submarine sensors, autonomous underwater vehicles (AUV) and oil well drilling platform, including network security,
network protocol, location technology, time synchronization and etc. key technologies [4,5]. Oil well drilling platform can be connected to backbone networks such as Internet, extract real-time data from multiple underwater remote devices and transmit information [6]. Currently, the research challenges of the network include bandwidth limited, communication capacity limited, low efficiency, and the easily damage of underwater sensors [3,7].

Network Design of Wireless Communication for Subsea BOP Stack

The network of underwater acoustic wireless communication has been designed with OFDM (Orthogonal Frequency Division Multiplexing) module and PLC (Programmable Logic Controller) module. The module of OFDM includes underwater channel estimation technology, diversity reception technology, equalization technology, QPSK modulation technology, OFDM modulation and demodulation technology, error control coding and decoding technology, anti-time-varying multipath technology, Doppler compensation technology and so on. Its working process is shown in Figure 1.

![Figure 1. The module of OFDM.](image)

The module of PLC includes well shut-in controlling at sea and subsea data acquisition controlling. Its PLC type is S7-300 made in Siemens Co. I/O of the PLC module has also been designed as follows Figure 2. The PLC codes of well shut-in controlling at sea have been programmed as follows Figure 3. The PLC codes of subsea data acquisition controlling are similar to those of well shut-in controlling, thus they are not going to be gone into detail here.

![Figure 2. I/O distribution map of the PLC module.](image)
Optimization of Subsea BOP Stack Control System

Subsea BOP Stack Control System Based on Wireless Communication Network

As shown in Figure 4, a new control system of subsea BOP stack based on wireless communication network consists of a central control unit set on at sea and several subsea control units. The central control unit is composed of database servers, workstations, industrial control computers, virtual private network (VPN) servers, genius three redundant control modules (GMR) owning in PLC, modems and acoustic transducers. Subsea control units are composed of underwater electronic modules, A/D converters, subsea wireless sensor components and hydraulic control subgroup, among which the underwater electronic module including a micro-PLC programmable controller, modems and underwater acoustic transducers. The new control system uses double redundancy Industrial Ethernet to realize communication and connects to the central control unit, the driller console and the captain console by STP. The underwater acoustic transducers, modems and the micro-PLC programmable controllers in the subsea control box are connected to the same bus and are also connected to hydraulic control systems by the or-gate logic circuit.
Industrial control computers can realize real-time on-line monitoring, receive the instruction information from the central control unit, the driller console and the captain console, and receive the data information of underwater oil well equipment and surrounding oil production environment such as pressure, temperature and flammable gas detection sent by the PLC module of subsea data acquisition controlling.

PLC programmable controllers can compare, analyze and process the data information of pressure, temperature and others and then get the corresponding results which can control the startup of automatic shut in and alarm. At the same time, PLC programmable controllers can also send the data information to the industrial control computers and when the data information was displayed on the human-computer interface, it also can be referenced by related staff.

As shown in Figure 5, the new system has two optimizations in the hydraulic circuits of the automatic shearing subsystem of oil well drilling pipe. On the one hand, in order to avoid the risk of switching between "forbidden" state and "standby" state of the existing system by hand or ROV operation in advance, and also to increase the security and reliability of the new system, using the automatic shearing electromagnetic direction valve of normally open type instead of the reversing valve of original pilot type. The valve connects mechanical (LMRP platform) operation valve, and it is energized in the absence of danger or the working time of normal oil well drilling operation, which means the valve is closed and the automatic shearing subsystem of oil well drilling pipe is in the "forbidden" state; When the emergency occurs, the valve loses power, which means the valve is open and the automatic shearing subsystem of oil well drilling pipe is in the "standby" state. This improvement enables automatic switchover from "forbidden" to "standby" or from "standby" to...
"forbidden". On the other hand, the subsystem designed by the electromagnetic valve of normally closed type which is controlled by the micro-PLC forms another hydraulic circuit. The micro-PLC which is the module of subsea data acquisition in the control box controls whether the valve of normally closed type is energized. In this improvement, the micro-PLC control allows the automatic shearing subsystem of oil well drilling pipe to be activated when most of the main control system fails and the LMRP is not disengaged caused by blowout, which further improves the security and reliability of the new system.

![Hydraulic circuit diagram of automatic shear system.](image)

The micro-PLC performs a delay start-up program each time when it had received the digital signal sent by wireless sensors and if the feedback signal of oil well drilling platform was received within the set time range, the oil well shut-in program wouldn’t be started up and the delay program would be terminated. If no signal was received, the micro-PLC would make a judgment based on the digital signals emitted by the wireless sensor units and it should decide whether the normal oil well shut-in program or the automatic shearing subsystem of oil well drilling pipe was started up. The decision mentioned above was worked only when the subsea control box is out of contact with the oil well drilling platform and all the signals are interrupted.

**Realization of the New Subsea BOP Stack Control System**

The working flow of the new subsea BOP stack control system is shown in Figure 6.

![Work flow chart of subsea BOP stack.](image)
The programming language of the working flow is LAD (Ladder Diagram) based on S7-300Step7 software v5.5. The LAD of well shut in program of the system is shown in Fig. 3. The I0.0 switch is the master switch of program start-up. When the program of well drilling is executed, the I0.0 is turned on and then the master control program of well drilling runs. At this time, if any one of M100.0, M100.1, M100.2 and M100.3 turns on, and it is normal of the data from the wireless sensors in charge of oil temperature and oil pressure and others which are the detection elements of PLC control system on the platform, then the working state is safety state, so the shut in program doesn’t work; and it is abnormal of the data from one of the sensors, then the working is unsafe, so the shut in program begins to work under controlled blowout; and it is abnormal of the data from two or more of the sensors, then the working is rather unsafe, so the shut in program begins to work under uncontrolled blowout; and it is abnormal of the data from all the sensors, then the working is very dangerous, so the shut in program runs and Ram Preventer works or oil well has to be shut in immediately.

**Summaries**

In order to meet the demand of sustainable development, and to improve communication of control system quickly, the control system of subsea BOP stack has been designed based on underwater acoustic wireless communication network.

There are two advantages of the optimized control system of subsea BOP stack:

1. With the subsea wireless communication network, the new control system realized the real-time monitoring of oil well equipment and oil production environment, and ensured the safety of personnel and equipment in the process of subsea oil production;
2. Based on PLC controlling, the new control system not only greatly improves the degree of automation and itself reliability but also fits for quick and sensitive remote control of all signal. Therefore it is very powerful for oil extraction in the difficult areas with rich oil.

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