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An approach to operational risk modeling and estimation of safety levels for deep water work class remotely operated vehicle—A case study with reference to ROSUB 6000

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Abstract

This paper presents a quantitative approach to operational risk modeling and estimation of safety integrity levels, required for the deep water electric work class remotely operated vehicle with reference to ROSUB6000 developed by the National Institute of Ocean Technology, India. ROSUB6000 is used for carrying out bathymetric surveys, gas hydrate surveys, poly-metallic nodule exploration, salvage operations, and meeting emergency response situations. The system is expected to be in operation for a period of 300 h per year, and has to be extremely safe and reliable. Methods and models for the quantitative assessment of operational safety and estimation of safety integrity levels for ROV are seldom available in the deep water intervention industry. The safety instrumented functions implemented in the ROV should be able to meet the SIL requirements of specific mission. This study indicates that the required safety factors are implemented into the design of the state-of-the-art ROV ROSUB 6000, considering IEC 61508/61511 recommendations on Health, Safety and Environment and it is found that the system is able to meet the required SIL for seven identified functions. This paper gives the design and safety engineers in the ROV industry, an overview of the numerical operational risk assessment methods and safety-centered ROV engineering.

Keywords: Remotely operated vehicle; HSE; Safety integrity level; Safety instrumented function.

1. Introduction

Work class remotely operated vehicle (ROV) support is found to be highly essential in the oil and gas sector [1], deep water research, and offshore energy sectors [1] where the oil and gas sector is accountable for 75% of ROV usage in drilling, exploration and subsea infrastructural developments [2]. The global annual expenditure on work class ROV operations is set to increase from $1.6 billion in 2013 to $2.4 billion in 2017, a compounded annual growth rate of 11.3% [1]. The world fleet of work class ROVs has grown from 641 units in 2011 [3] to 1102 units in 2013 [4]. This is largely due to the move toward deeper waters and more complicated offshore field development programs [5–8]. The essential use of work class ROV in deeper water was clearly demonstrated during the Macondo well head blow-out in the Gulf of Mexico [9] which demanded safe and reliable operation in the challenging environment. This demands the need for relevant safety standards and procedures to be implemented in the fast growing subsea intervention industry, where the vehicle risk tolerance levels and associated safety requirements are dictated by the mission for which the vehicle operations are called. The required safety levels for the intervention system are normally dictated by the Health, Safety and Environmental (HSE) regulations already in place which is usually described by the safety integrity levels (SIL) based on IEC 61508 and 61511 standards [10–12] and the operational SIL of the ROV needs to be in compliant with the required SIL. Thus a quantitative, risk based, operation specific assessment of the vehicle's SIL is required, so as to ensure confidence in the use of ROV for the specific operation. Even though, safety assessment by qualitative methods for the required safety levels in offshore environments [13] and surface vessels [14] exist, such methods are seldom practiced in the ROV industry where

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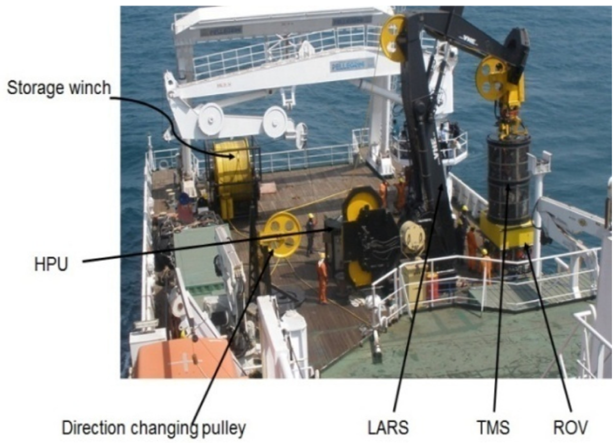

Fig. 1. View of the ROSUB 6000 system prior to launch.

safety assessment has a high level of uncertainty due to the insufficient reported failure data which has been a major concern for risk related decision support. Novel decision making techniques are required to make the design and operation decisions efficiently and in the absence of which, it might be difficult to compare the design costs and operational benefits. Thus, the need for suitable risk assessment and quantitative safety models based on HSE are required. The CAPEX and OPEX of the ROV are decided by the frequency of maintenance required to upkeep the SIL. Thus the maintenance expenditure could be greatly reduced by safety centered design practices. This paper presents an approach to the operational safety modeling and estimation of SIL for deep water electric work class ROV, with reference to the ROSUB 6000 designed by the National Institute of Ocean Technology (NIOT).

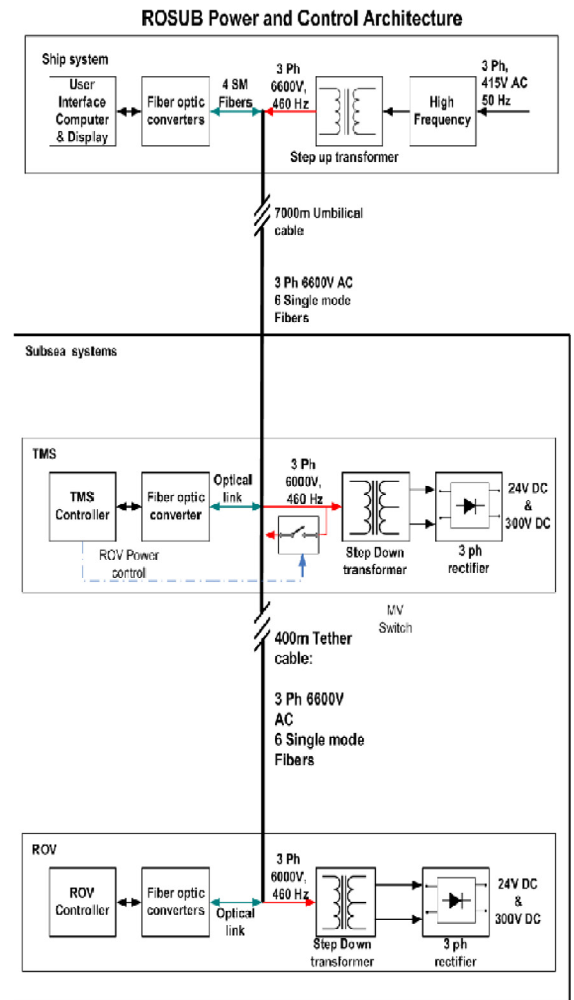

Fig. 2. Electrical and control architecture of the ROSUB 6000 system.

2. System description

NIOT has developed an electric work class ROVROSUB 6000 for carrying out deep sea operations such as bathymetric surveys, gas hydrate surveys [15,16], poly-metallic nodule exploration [17] and salvage operations. The ROSUB 6000 system comprises of a remotely operable vehicle (ROV), tether management system (TMS), launching and recovery system (LARS), ship systems, control console, instrumentation, control and electrical system, control and operational system [15,18].The vehicle is equipped with two electrically powered hydraulic actuated manipulators, which can handle a pay load of 150 kg intended for mounting scientific and mission oriented systems.

Fig. 1 shows the overall architecture, where the work-class ROV and the TMS are docked together, and ready for launch from the mother vessel, using the LARS. 6000 m of umbilical cable is housed in a hydraulically operable deck storage winch, and its operation is synchronized with the LARS. The LARS handles the ROV-TMS docked system and undocks it below the splash zone. As the system reaches the desired depth, the ROV is caged out of the TMS. The ROV is propelled by thrusters, and can be operated in any desired direction from the pilot command from the ship. Manipulators are used to carry out subsea tasking operations. After the completion of the task the ROV shall be docked back to the TMS subsea and the system is recovered to the ship.

Fig. 2 indicates the power and control system architecture in the TMS, ROV and the ship. Ship power at 400 V and 50 Hz is transformed into 6600 V and 460 Hz using a standard frequency converter and a step up transformer. Electro-optical connectivity between the ship and TMS is achieved by a 6000 m umbilical cable. The connectivity between the TMS and ROV is realized by the 400 m long tether cable, and a ruggedized pressure compensated medium voltage switch [19]. Subsea power converters in the TMS and the ROV convert 6600 V at 460 Hz to the power level required for the subsystems. The system was developed with the aim of carrying out 300 h of deep sea operations per year, with reliability as the key driver, and was identified to have an MTBF of 4.9 years and 6.2 years for ROV-TMS docking and manipulator operations respectively [6–8]. Since its inception in 2007, the system has undergone 37 dives, of which 13 dives were at depths greater than 1000 m [6–8].

The design depth qualification of the system was carried out at the polymetallic nodule site at the Central Indian Ocean