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RELIABILITY

Redundancy and Criticality Assessment (RCA) System Applied in Deep Water Operations

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Introduction

The paper will focus on a new system developed as part of a "Deep water development program" run by Kongsberg Simrad aiming to improve the reliability of DP operations. Today the accuracy of station keeping is no longer the problem; what is worrying is the overall reliability of the whole DP based operation. The program has focused on this issue especially in the context of deep water drilling.

Deep Water Program

The DP development program is a part of a large national Norwegian research program focusing on deep water operations with special emphasis on exploration drilling at the Voring plateau and More basin in the Norwegian sea. It is funded by the Norwegian research counsel, oil companies operating on the Norwegian continental shelf and the system industry. The Kongsberg Simrad project has addressed the following main areas:

- DP reference systems and reference system processing in deep water operations.
- Support tools to enable the DP operators to get a clear picture of the current operational situation aiding them to take the appropriate actions.
- Offshore test for evaluating the results of the program (to be carried out onboard the intervention vessel Botnica of DSND in November 1998)

A description of the program and its main results are documented in [1].

Several DP incidents in the past have shown that misinterpretations of alarms and other observed process irregularities as well as inadequate actions taken by DP operators play an important role in the deterioration of operational reliability. This problem may be considered as a matter of professional skills and overall knowledge of DP operations in relation to the vessel and its machinery, equipment, sensors, the environment, the behaviour of the vessel, seamanship etc. Since the complexity of a modern vessel and information presented to operators have grown quite dramatically, it is a very demanding task to act as a DP operator. One of the main goals has been to assist the operator in avoiding criticality to take place as a result of malfunctions by assuring that the level of redundancy (no criticality) is maintained during the operation, and in assessing the actual situation, not to overload him with more unessential information. By getting proper decision making tools (which the operators know how to use) the risk of experiencing operator errors should be reduced.

The operator support toolkit consists of:

- On-line DP capability analysis estimating the maximum environmental condition (in terms of wind, waves and current) in which DP operations can be performed taking into account thruster and power failures
- On-line drift-off analysis estimating the time to go until a drift-off caused by equipment failures exceeds operational limits
- Redundancy and Criticality Assessment (RCA) system focusing on the setup and supervision of the ship machinery, thrusters and auxiliaries as well as the DP system itself and its sensors and interfaces

The main activities related to reference systems and the on-line DP capability- and drift-off analysis systems may be found in [2]. This paper is concentrating on the RCA system and its use.

RCA System

The RCA system is an integrated on-line fault monitoring and criticality assessment tool which monitors and confirms that the resources required for a specified mode of operation are available. In particular, this applies to the vessel modes defined for DP operations, with corresponding definitions for DP equipment and machinery required to perform the selected station-keeping operation.

The typical operational modes taken into account may be:

- DP mode 3 — According to DP equipment class 3 requirements (IMO regulations)
- DP mode 2 — According to DP equipment class 2 requirements (IMO regulations)
- DP mode 1 — According to DP equipment class 1 requirements (IMO regulations)
- Manoeuvre mode — According to the need of operational thruster power for smooth manoeuvring
- Transit mode — Power requirements/configuration for transit
- Harbour mode — According to the requirements for power generation in the harbour

Modes will be defined tailored to a specific vessel and its main purpose, e.g. drilling, offshore loading and production.

The RCA system is a part of an integrated thruster and vessel control system (IAS). It utilises the instrumentation and control functions which are normally built into a modern DP-vessel. Thus any additional instrumentation or physical installation such as computers, sensors and cabling is not required. The RCA functions are added to the basic IAS in order to continuously verify that the equipment is set up correctly for the intended DP operation. In case of a detected malfunction, it will report to the operator according to the criticality of the event.

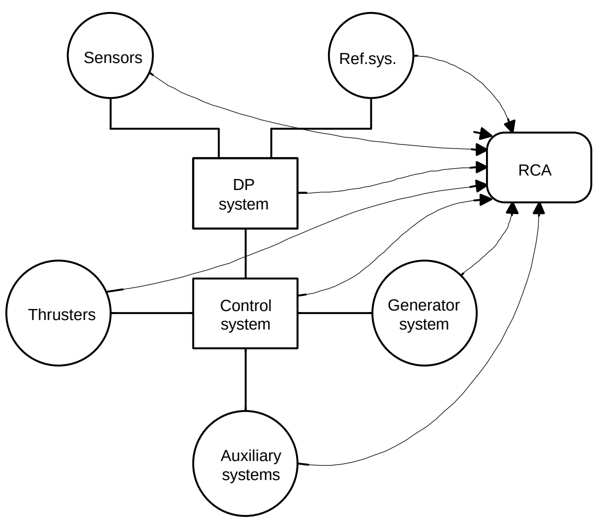

Figure 1.The RCA “network”

The RCA system will monitor the status of all equipment taking part in the station-keeping operation, see figure 1:

- Propulsion / thruster units
- Electric power generation system
- Auxiliary process systems (fuel, lubrication, cooling water, hydraulic oil, start air, etc.).
- DP-control systems, reference systems and sensors
- Vessel automation systems.
- Availability of standby / backup subsystems (e.g. standby pumps)

The status of the equipment is compared with the current vessel mode requirements, and discrepancies are reported.

The RCA-system will support the operator with (see figure 2):

- Mode control

  which automatically establishes the selected mode (as a part of the IAS)

- Equipment displays

  which give "top level" information on the present machinery condition and, in case of a malfunction, give messages on whether the present operation can be maintained or not. The information presented is filtered, i.e. only crucial information is presented in order not to distract the operator with a huge amount of details during a critical situation. *The RCA is not another alarm system*. The information is primarily presented according to the DP operator's needs, not the

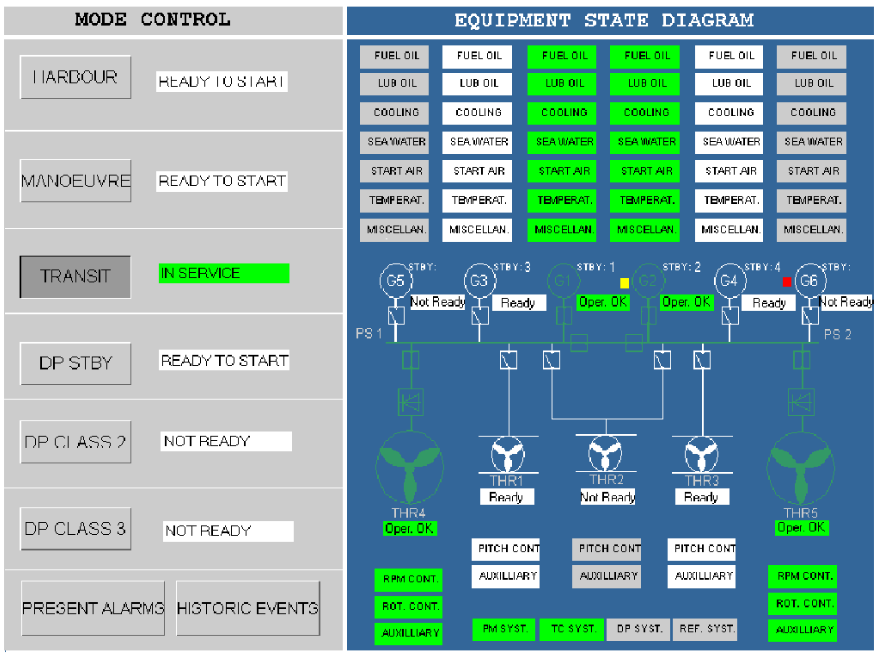

Figure 2. Main RCA view

The RCA monitoring functions are defined through a set of process unit (typically generator and thruster assemblies) and sub-units (typically parts of a thruster / generator and auxiliaries) descriptions, where Cause & Effect matrices for each part is defined. For a DP vessel typically about 1000 signals are taking part in the RCA monitoring.

The status of the DP system (including the backup system for class III), its reference systems, sensors and critical alarm conditions are taken into account according to the IMO guidelines.

The RCA for an actual delivery is defined by identification of the modes required for the vessel. Then the main equipment units which are vital for the modes are listed, together with the sub-systems for each equipment unit. A set of EXCEL worksheets are prepared based on predefined forms. These sheets contain:

- Vessel configuration
- Requirements for each mode (e.g. number of generators, thrusters, bus-tie configuration)
- Connections to the Mode control functions
- Cause & Effect matrices for each main equipment unit and their auxiliary systems.

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The Cause & Effect matrix specifies the status and alarm signals which are important for the performance of the actual unit, and how they contribute to the state of this unit. Signals are selected from the actual system signal database.

The result of the RCA specification is then automatically generated as a set of connected function modules (see figure 3) and integrated with the basic IAS system. An example of a Cause & Effect matrix for a thruster is shown in figure 4.

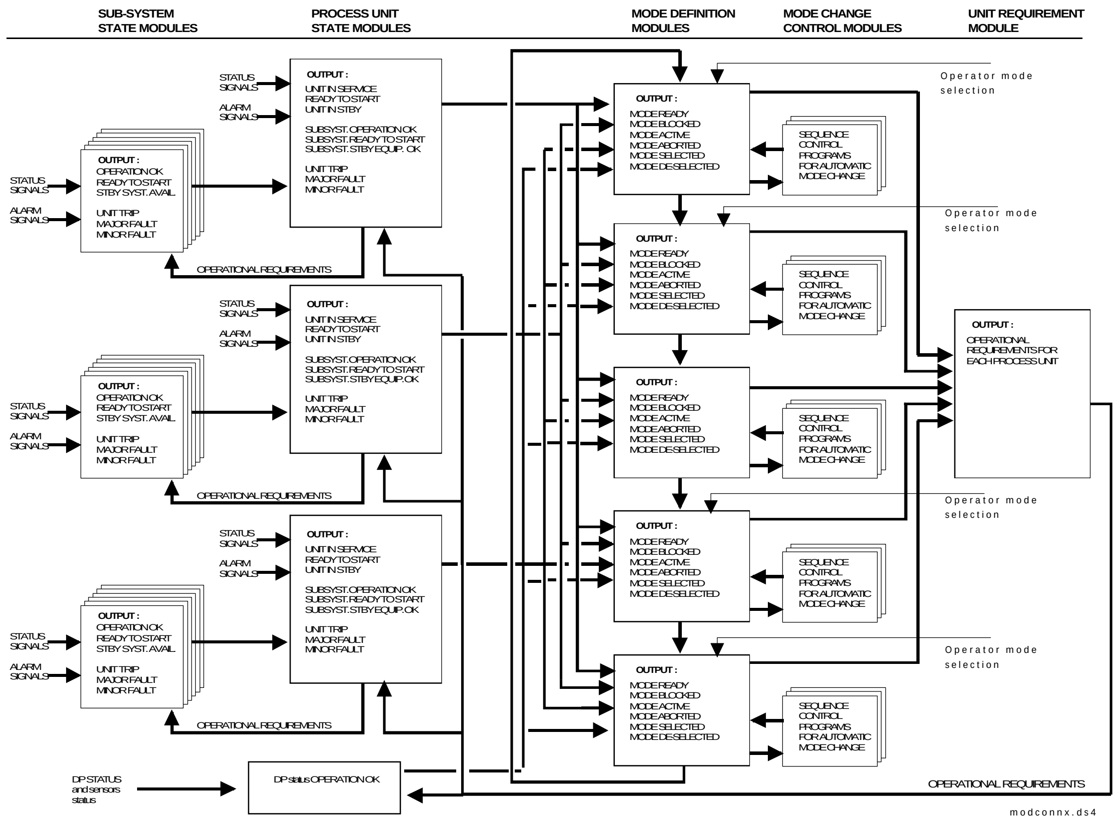

Figure 3. RCA monitoring modules

Vessel		FINNYARDS	PCU #	10
Tag name		pu_THR4		
Level		RCA_PU		
Revision		19/4/98		
Comments		Process Unit for Azipod 1/Thr 4		
Unit name		Thruster 4		

vsn 1.0

RCA-PU STATE DIAGRAM

Tag	#	Description	TermName	Test	IN SERVICE				UNIT IN STANDBY				UNIT READY TO START				TRIPPED		MAJOR FAULT		MINOR FAULT	
				OP1	1&2				1&2				1&2									
				OP2	&	&	&	&	&	&	&	&	&	&	&	&						
					Cause & Effect matrix																	
EA3634	1	THR4 BREAKER AUX VOLT FAULT	Meas1						C				C									
XE3635	2	THR4 BREAKER Remote, ReadyClose	ReadyClose		X								X									
XE3635	3	THR4 BREAKER TRIPPED	CBTripped														X					
TIAH3556an	4	THR4 WINDING 1U TEMP	H																X			
TIAH3559an	5	THR4 WINDING 1U TEMP	H																X			
TIAH3557an	6	THR4 WINDING 1V TEMP	H																X			
TIAH3560an	7	THR4 WINDING 1V TEMP	H																X			
TIAH3558an	8	THR4 WINDING 1W TEMP	H																X			
TIAH3561an	9	THR4 WINDING 1W TEMP	H																X			
EIAH3632an	10	THR4 CURRENT	H																X			
XA3636	11	THR4 EMERGENCY STOP	Meas1														X					
XI30003	12	SM1 INVERTER RUNNING	Meas1		X																	
XA3002	13	SM1 INVERTER ALARM	Meas1														X					
XA3001	14	SM1 INVERTER FAILURE	Meas1						C	C	C						X					
XI30002	15	SM1 READY FOR START	Meas1						X	X	X											
############		END line must always be inserted																				

OP1: Combination of columns for each state
OP2: Logical operator to be used for each column within a state.

Tag 'an' suffix: fetch the corresponding alarm state from this signal

Operator conventions
& - logical AND
V - logical OR
Matrix notation:
X - Include this signal here
C - Include complemented signal
Empty - ignore

Figure 1. Cause & Effect matrix for a thruster

On the Use of RCA in DP Operations

The equipment requirements are related to the type of operation to be performed. On the Norwegian continental shelf the Norwegian Petroleum Directorate applies the NORSOK standard [3] to define equipment class (IMO class) to be used. An extract of these requirements is give in the table below.

OPERATION	EQUIPMENT CLASS	NOTES
Drilling	3	Applies to all drilling in hot zones
Subsea well workover	3	
Production of hydrocarbons	3	Workover operations entailing hydrocarbons on deck
Wireline operations on subsea wells	2	With subsea lubricator
Well stimulation	2	
Manned subsea operations	3	For diving inside structures etc.
Unmanned subsea intervention with ROT	2	Inside hot template
Construction activities in general, inside 500 m safety zone	2	
Construction activities in general, outside 500 m safety zone	1	

When running a class III operation the main equipment requirement would be (not complete):

- A minimum number of running generators and thrusters distributed on the different switch boards in such a way that the worst case single point failure (including fire or flooding of a compartment) should not cause insufficient thrust or power for DP. The thruster / generator configuration will depend on the environmental condition and vessel heading. Hence no DP consequence analysis alarm indicating a possible drift-off as a result of worst case single point failure must be present.
- A main redundant DP system fully operational with at least three reference systems and gyro compasses in service.
- A backup DP system fully operational with at least one reference systems and gyro compass in service.
- An independent manual thruster control system or joystick in operation.

For a class II operation no backup DP is required and single point failure cased by fire and flooding is not relevant.

When the requirement for a certain DP mode is established, the Mode Control (as a part of the IAS) can automatically start/stop the thrusters, generators and auxiliaries needed to enter the mode. In addition a set of minimal DP requirements (necessary for the DP to work) must be fulfilled before a specific DP mode will be ready to start. If the full set of DP requirements according to the IMO guidelines should not be met during the operation the RCA will alert the operator.

A typical requirement matrix which must be fulfilled in order to enter (and stay) in the different modes (see the Min. rows) and requirements to avoid mode alarms (see the Alarm row) are shown in the figure below.

DP mode (class)		Main DP OK	Thruster control OK	Backup DP OK	No. of Gyros ready [1]	No. of VRS ready [2]	No. of Ref. sys. OK [3]	Cnsq alarm [4]	Major DP alarm
I	Min	Single	Yes	NA[5]	1	1			
	Alarm						< 1	NA	Yes
	Min	Dual	Yes	NA	1	1	1		
II	Alarm				3	3	< 3	Yes	Yes
	Min	Dual	Yes	Single	1	1	1		
III	Alarm				3	3	< 3	Yes	Yes

When the DP system is up and running according to the built in requirements, the operator will get an indication that the mode is active and a safe operation can take place. The mode will be kept as long as the minimum requirements are met, otherwise the operator will be alerted that DP operation is not possible any more. If the mode alarm requirements are violated, alarms will be issued showing that the mode requirements are not fulfilled anymore and actions have to be taken. Any violation of the alarm- and minimum mode requirements are indicated graphically on the main RCA view, figure 2.

Typical major DP alarms are:

[1] No. of gyros for main DP and backup, e.g. 3 + 1 means 3 for main DP and 1 for backup
[2] See footnote 1
[3] Accepted by the DP system, see also footnote 1
[4] DP consequence analysis alarm
[5] Not applicable

- Out of position or heading
- Insufficient thrust
- Insufficient power

If e.g. a DP consequence analysis alarm is issued, the DP operator must take immediate action; either preparing for an operation shutdown or start additional thrusters or generators. By watching the On-line drift-off analysis view on the DP system, he will immediately know how fast he will be drifting off and the available time until the vessel is out of position (or heading).

During the operation the operator should also look at the On-line DP capability view to see what margins (in terms of changes in weather condition) he has if this worst case single point should occur. If the margin is assessed as too low, more generators or thrusters should be started.

Conclusion

The presented RCA system is a “complete monitoring system” for DP operated vessels implemented as an add-on to the IAS, integrating information from both the vessel automation system, the manual thruster control system and the DP. It co-operates with mode control which automatically starts all necessary units to run a specific mode. The RCA monitors any discrepancies from the mode requirements and alerts the DP operator showing whether the current job is being performed safely within the specified redundancy and criticality requirements or not.

References

[1] Kongsberg Simrad, Seatex — Reliability of DP Operation in Deep Water

[2] Jenssen N.A — Improved DP Performance in Deep Water Operations Through Advanced Reference System Processing and Situation Assessment. Paper at MST 1997

[3] NORSOK — Marine Operations, J-003, Rev. 2, August 1997