Components redundancy in power and propulsion systems installed onboard platform supply vessels

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ABSTRACT: Comparative analysis of two power and propulsion plants installed onboard Platform Supply Vessels (*PSV*) in redundancy aspect have been done. Offshore ships with similar design and purpose with differences in number and location of dynamic positioning thrusters (for keeping desired heading and position of the ship) have been presented. Design of the power plant onboard these vessels according to rules of International Maritime Organization and one of the classification societies have been shown. Possibility of particular redundancy model (using complex number plane) application for modeling and compare of different *PSV* vessels power and propulsion plants has been presented. Minimum requirement for different consequences classes dynamic positioned vessels power plants has been presented. Possibility of presented model application for system reliability estimation has been pointed out.

1 INTRODUCTION

1.1 *Classes of dynamically positioned vessels*

Most of offshore vessels inter alia Platform Supply Vessels are fitted with dynamic positioning (*DP*) systems. The equipment of vessels with *DP* system, that is vessels capable of maintaining a given position and heading in a required range while performing technological operations at sea has to comply with certain regulations and requirements [ABS 1994, DNV 1990, LRS 1997]. *International Marine Organization* (*IMO*) regulations apply to ships built after 1 June 1994 and divide ships with automatic positioning into three classes. The *IMO* classification does not cover ships with manual or semi-automatic position control. Levels of redundancy are defined in an *IMO* circular [IMO 1994] and subsequent detailed guidelines published by The International Marine Contractors Association (*IMCA*) [IMCA 1999a, IMCA 1999b].

Equipment classes for *DP* vessels as defined by *IMO* are as follows:

- Class 1 – loss of position (drifting off a given position and/or heading due to a *DP* system failure) may occur in the event of a single fault.
- Class 2 – loss of position (drifting off a given position and/or heading due to a *DP* system failure) should not occur from a single fault of an active component or system such as generators, thruster, switchboards, remote controlled valves etc. But may occur after failure of a passive component such as cables, pipes, manual valves etc. Basic requirements of this class according to *Det Norske Veritas* (*DNV*) classification society are given in Table 1.
- Class 3 – loss of position (drifting off a given position and/or heading due to a *DP* system failure) should not occur from any single failure including a completely burnt fire sub-division (e.g one of the power plants) or flooded watertight engine room compartment. Single faults also include single inadvertent act by any person on board the *DP* vessel.

1.2. *Dynamic Positioning system decomposition*

Platform supply ships are usually Class 2 *DP* vessels. Dynamic positioning system S consist of: E_{S1} – automatic system of dynamic positioning supervision; E_{S2} – ship's electric power plant; E_{S3} – ship's propulsion system; E_{S4} – emergency electric power supply; E_{S5} – reference sensors system; E_{S6} – the other components of *DP* system. It can be presented in the form:

$$S = \{E_{S1}, E_{S2}, E_{S3}, E_{S4}, E_{S5}, E_{S6}\} \tag{1}$$

In the further part of the material compareative analysis of components power and propulsion plant components redundancy installed onboard two selected *PSV* vessels. Thes sips are fitted with *DP* systems according to the Class 2 *DP* requirement.

Table 1. *DNV DP Class 2* (*AUTR*) requirements [DNV 1990].

Subsystem or component			Minimum requirements for *AUTR* class notification
Power system	Generators and prime movers		Redundancy in technical design
	Switchboard		1 with bus-tie
	Bus-tie breaker		1
	Distribution system		Redundancy in technical design
	Power management		Yes
Thrusters	Arrangement of thrusters		Redundancy in technical design
	Single levers for each thruster at main *DP* control centre		Yes
Positioning Control System	Auto control: number of *DP* computers		2
	Manual joystick system with auto heading		Yes
Sensors	Position reference systems		3
	External sensors	Wind	2
		VRS	2*)
		Gyro compass	3
	UPS		2
	Printer		Yes
Alternate control station for positioning control back-up unit			No

*) Where necessary for the correct functioning of position reference systems, at least three vertical reference sensors are to be provided for the notation *AUTR*

Analyzed ships are built based on similar hulls design, which are *UT 755* and *UT 755L*. One of these ships is shown in Figure 1. Main technical data of these vessels are presented in Table 2. Power and propulsion plants configuration of these vessels are presented in Figures 2, 3. Ships are equipped with proper components according to redundancy requirements to provide of the desired level or operational safety and system reliability especially during an offshore operation [Arid 2001, HSE 2004].

Power and propulsion plant of the hull design 755 vessel is shown in Figure 2. The system consists of basic elements:

- two main propulsion sets: main diesel engine *Rolls-Royce Bergen KRM-9*, reduction gear, shaft generator, shaft clutch (which allows to disengage propeller and shaft generator operation when the ship is alongside the quay), Controllable Pitch Propeller (*CPP*);

Figure 1. Platform supply vessel general view.

Tab.2. Technical data of analyzed vessels [RRM 2001].

Characteristics	Vessel of *UT 755* Design	Vessel of *UT 755 L* Design
Main Particulars		
LOA	67,0 m	71,9 m
LPP	61,8 m	66,8 m
Breadth Moulded	16,0 m	16,0 m
Depth Main Deck	7,00 m	7,00 m
Min Draught	4,80 m	3,80 m
Max Draught	6,00 m	5,83 m
DWT (max draught)	3000 t	3084 t
GRT	2237 t	2401 t
Net Tonnage	951 t	1069 t
Performance		
Max speed	14, 7 knots	14,2 knots
Fuel consumption per day	Sailing: 18 t @ 14,7 knots Standby: 4 t In port: 1 t	Sailing: 18 t @ 10 knots Standby: 4 t In port: 1 t
Machinery and Propulsion		
Main Engines	2 x *Rolls-Royce Bergen*, 5450 BHP	2 x *Rolls-Royce Bergen*, 5450 BHP
Auxiliary Engines	2 x 250 kW, 450 V, 60 Hz	2 x 320 kW, 450 V, 60 Hz
Emergency Generators	1 x 48 kW, 450 V, 60 Hz	1 x 65 kW, 450 V, 60 Hz
Shaft Generators	2 x 1600 kVA, 380-450 V, 60 Hz	2 x 1600 kVA, 380-450 V, 60 Hz
Main Propellers	2 x *CPP*	2 x *CPP*
Tunnel Bow Thrusters	1 x 800 BHP	2 x 800 BHP
Azimuth Bow Thrusters	1 x 800 BHP	N/A
Tunnel Stern Thrusters	1 x 800 BHP	2 x 800 BHP
Rudders	2 x *HighLift*	2 x *HighLift*
Dynamic Positioning		
DP system	*DP II – Kongsberg Simrad SDP21*	*DP II – Kongsberg Simrad SDP21*
DP References	2 x *DGPS*, 1 x *Fan Beam*, 1 x *IALA Land Station*	2 x *DGPS* 1 x Fan Beam,
Joystick	Fitted	Fitted

- two auxiliary diesel generating sets *Volvo Penta TAMD121*;
- one fore azimuth thruster;
- one tunnel bow thruster;
- one tunnel stern thruster.

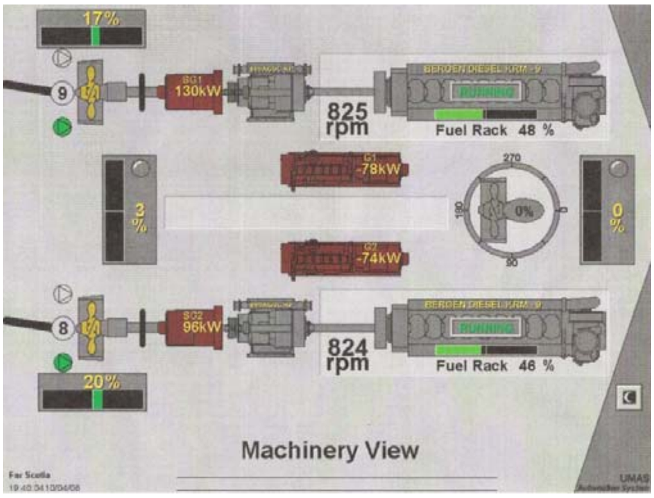


Figure 2. Power and propulsion system of UT 755 hull design vessel.

Power and propulsion plant of the hull design 755L vessel is shown in Figure 3.

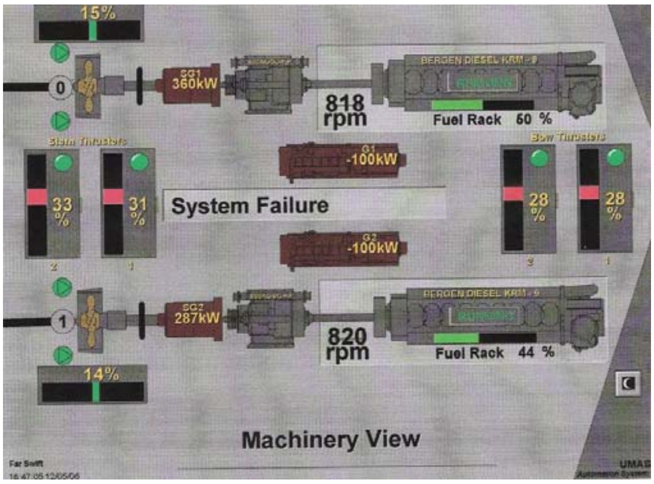


Figure 3. Power and propulsion system of UT 755L hull design vessel.

The system consists of basic elements:

- two main propulsion sets: main diesel engine *Rolls-Royce Bergen KRM-9*, reduction gear, shaft generator, shaft clutch (which allows to disengage propeller and shaft generator operation when the ship is alongside the quay), Controllable Pitch Propeller (*CPP*);
- two auxiliary diesel generating sets *Caterpillar D343*;
- two tunnel bow thrusters;
- two tunnel stern thrusters.

2 PARTICULAR REDUNDANCY MODEL

2.1 *Redundancy model briefing*

For the reliability structure modeling of *PSV* vessels power and propulsion systems, presented in previous chapter, redundancy model proposed by authors [Chybowski & Nicewicz 2005, Chybowski & Matuszak 2006a, Chybowski & Matuszak 2006b] has been used. In order to model the redundancy in the system X the transformation $z(X, t)$ was introduced, which resulted in a pair of numbers, which is, respectively, equal to the number of basic components $p(X, t)$ and the number of standby components $r(X, t)$ w in the system X at the time t:

$$z(X,t) = [\,p(X,t), r(X,t)] \tag{2}$$

The function $z(X,t)$ can be presented on a complex plane as:

$$z(X,t) = p(X,t) + i \cdot r(X,t) \tag{3}$$

where $i = \sqrt{-1}$.

For a given moment of time $t \geq 0$ the total number of components $\Im(X,t)$ in the system X equals:

$$\begin{aligned} \Im(X,t) &= p(X,t) + r(X,t) = \\ &= \Im(X,0) - \Im_{REST}(X,t) \end{aligned} \tag{4}$$

where $\Im(X,0)$ = size of the system X with the assumed preset full availability of the system at the time $t=0$ equal to:

$$\Im(X,0) = \underset{t=0}{card}(X) = p(X,0) + r(X,0) \tag{5}$$

where $\Im_{REST}$ = number of components of the system X that have been failed till the time t.

2.2 *Redundancy model application*

Examples of a some reliability analysis aspects for subsystems of a *DP* system can be found in e.g. [Chybowski 2001, Chybowski 2002, Chybowski & Matuszak 2006a]; they will not be quoted here as they are rather lengthy. Basic *DP* subsystems components number requirements (basic and redundant components) for all classes, inter alia Class 2 *DP* Platform Supply Vessel are shown in Figure 4. Presentation is done with using of presented redundancy model, according to the *DNV* classification society rules.

A comparison of redundancy level in *DP* systems on ships belonging to any of the equipment class is possible through, e.g. the introduction of the coefficient $\Im_{real}$, that is equal to the maximum number of system components in the up state that could be observed during their operation:

$$\Im_{real}(X) = \max_{t \to \infty} \underset{t}{card}(X) \tag{6}$$

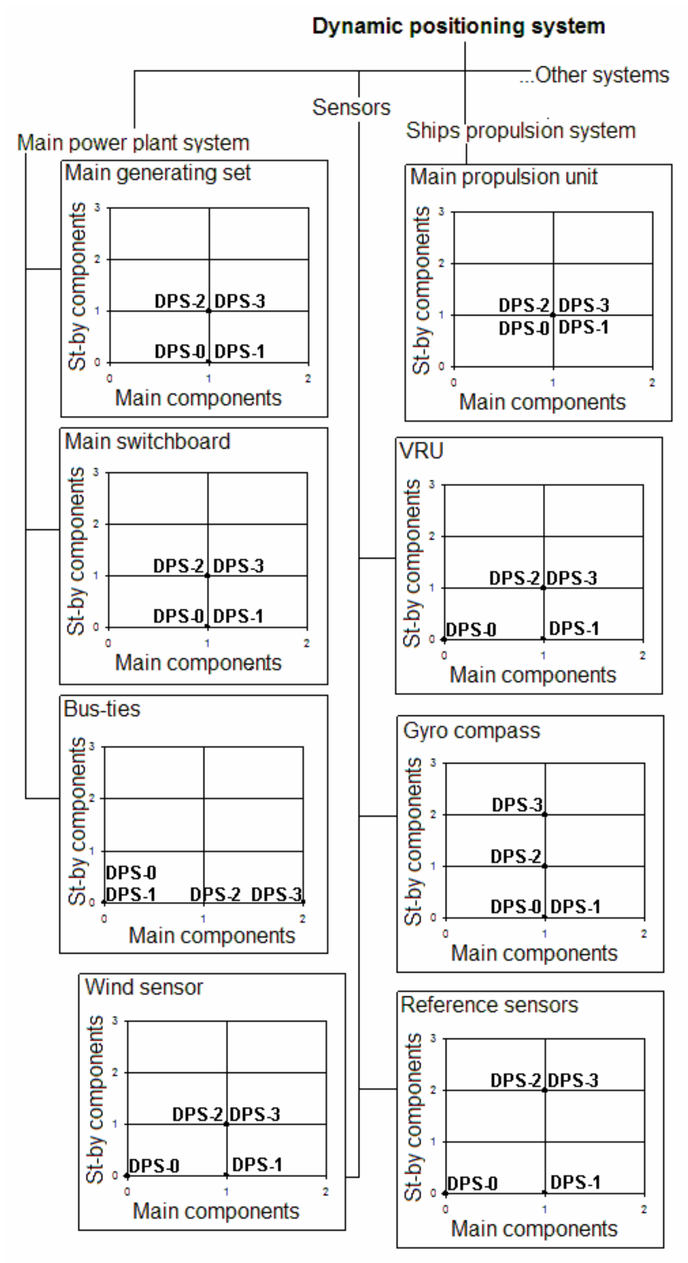
Recommendations of classification societies refer to the required minimum number of specific components $\Im_{kr}$, i.e. during the operation in the DP system at the moment of its full up state the real amount $\Im_{real}$ of a given sub-unit in the system X cannot be less than $\Im_{kr}$, which can be written as:

$$\Im_{real}(X) \geq \Im_{kr}(X) \tag{7}$$

Thus the value of the coefficient $\Im_{kr}$ for a specified system can be used for the description of redundancy in a specified subsystem on board a ship with a given equipment class. When this is referred to the required number of basic components $p(X, t)$, the size of standby components $r(X, t)$ in a specified system X, in any instant t cannot be less than the value:

$$r(X,t) = \Im_{kr}(X) - p(X,t) \tag{8}$$

Figure 4. *DP* vessels main subsystems components number requirements



3 FINAL CONCLUSIONS

Redundancy model presented in the paper is useful for system description and compare of different systems installed onboard offshore vessels within two different *DP* Classes as well as same *DP* Classes. It was shown on the basis of selected two platform support vessels. In this case, presented ships have small differences in the technical design and components configuration in the power and propulsion systems. Presented model can be further used for selected system reliability measures estimation.

The reliability of particular subsystems can be determined with the use of the proposed models of redundancy in a dynamic positioning system. In a general case, for the subsystem X with a threshold structure composed of identical components E_X, having taken into account the quantities presented with the use of the relationship, the system reliability at the instant of time $t \geq 0$ can be expressed as follows:

$$R(X,t) = \sum_{k=p(X,t)}^{n=\Im(X,t)} \binom{n}{i} \cdot [R(E_X,t)]^k \cdot \cdot [1 - R(E_X,t)]^{n-k} \tag{9}$$

For the threshold structure *k-z-n* composed of components $E_1, E_2, \ldots E_n$ with various reliability characteristics and the required number of components k ensuring the system is in up state, the system reliability can be presented in this general form:

$$R(X,t) = 1 - \sum_{k=r(X,t)+1}^{n=\Im(X,t)} \{(-1)^{k+r(X,t)+1} \binom{k-1}{n-i} \cdot \cdot \sum_{\substack{\forall P(E_{Li}) \\ Li \in \{1 \ldots n\}: \\ l1<\ldots<ln}} \prod_{j=1}^{k} [1 - R(E_{Li},t)]\} \tag{10}$$

It is necessary to develop presented topic and application of its together with other reliability analytical methods for different technical systems with high redundancy level e.g. offshore systems.

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