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# Reliability assessment of multi-megawatt capacity offshore dynamic positioning systems

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ABSTRACT

A reliable Dynamic Positioning (DP) system is the key requirement for critical offshore activities. This paper presents the quantitative reliability assessment for offshore multi-megawatt capacity electric DP systems based on the present technological maturity and the offshore industry-reported component failure rates. It is identified that the International Maritime Organization defined DP1, DP2 DP3 architectures with fully redundant power generators and electric variable speed thrusters could have mean time to fail periods of 0.3, 2.1 and 2.5 years respectively. In the analyzed DP2 architecture, the power generation cum management system, the computer control cum sensors system and the thruster systems contribute to 17%, 42%, and 41% of the total DP system failures. The results presented could be used for reliability-centered design and maintenance planning of multi megawatt capacity DP systems.



## 1. Introduction

Subsequent to the inception of the world's first drillship with the dynamic positioning (DP) capability in 1961, the DP technologies have matured, capable of providing offshore position-keeping with accuracies up to 2 m [1]. The impressive developments in high precision attitude sensors, environmental sensors, commercialisation of global navigation satellite systems, acoustic base line systems, computer-based control systems and algorithms combined with reliability-cantered design practices have resulted in highly accurate and reliable DP systems [2,3]. Reliability is the key requirement for DP systems used in vessels and platforms engaged in complex offshore developments and processes including drilling, diving, pipe lay, umbilical lay, Remotely Operated Vehicle (ROV) support, floating production, lifting and accommodation [4,5]. DP failures lead to accidents involving environmental impacts and economic losses. In case of Mobile Offshore Drilling Units (MODU), when Loss of Position (LOP) occur with wellhead riser angles > 7°, a controlled disconnect of riser from the well head needs to be performed for hazard avoidance [6]. Taking to consideration the Health, Safety and Environment (HSE) impacts due to DP failures and consequential LOP, DP systems are classified based on the regulations of International Maritime Organization (IMO) and Classification Societies (CS) such as DNV GL, ABS and LRS [7–9]. Even though IMO and CS have different class notations for DP systems, all the guidelines emphasize ultimately on the safety of offshore operations. The paper discusses the principles and advances in DP technology, identifies the industry-reported component failure rates for the DP subsystem components, presents the reliability modeling methodology and the identified mean time to fail (MTTF) for DP1, DP2 and DP3 system architectures.

## 2. Principle and challenges

The dynamics experienced by a vessel in the six Degrees of Freedom (DoF), including surge, sway and heave in the linear axis; roll, pitch and yaw in the angular axis is shown in Fig. 1. Kinetics involves the external forces acting on the vessel due to the action of the wind and waves; and the attitude changes experienced by the vessel due to the action of the external forces is defined by kinematics. According to IMO, the principle of the DP involves measuring the attitude changes of the marine craft and applying linear and angular forces to counteract the external forces and to maintain the vessel in a fixed position exclusively by means of active thrusters [7–9].

The kinetics and kinematics of vessel DP is based on the non-linear, low frequency, body-fixed coupled equations of motion in surge, sway and yaw degrees of freedom (DOF) represented in Eq. (1) [10].

$$M\dot{\nu} + C_{RB}(\nu)\nu + C_A(\nu_r)\nu_r + D_{NL}(\nu_r, \gamma_r)\nu_r + D_L\nu_r = \tau_{wind} + \tau_{wave2} + \tau_{thr} \quad (1)$$

Where M is the mass of the vessel; v is the velocity vector expressed as $v = [u,v,r]^T$; $v_r$ is the relative vector including the current; $C_{RB}$ and $C_A$ are the skew-symmetric coriolis and centripetal matrix due

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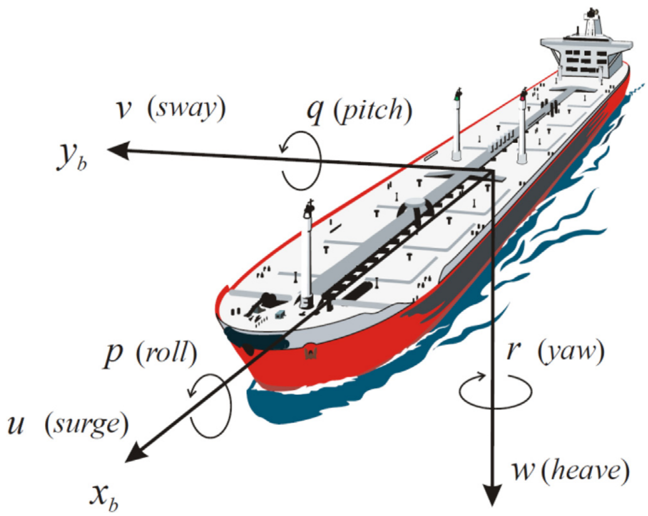


**Fig. 1.** Dynamics of an offshore marine craft [10].

to the water current; $D_L$ is the damping matrix caused by linear wave drift and laminar skin friction damping; $D_{NL}$ is the non-linear damping vector of the vessel in 3-DOF; $\zeta_{wind}$ and $\zeta_{wave}$ are the forces produced by the action of environment (including wind and waves). The control force vector required for position keeping of the vessel which is to be generated by the thrusters is represented as $\zeta_{thr}$.

The architecture of the vessel DP system including Computer Control and Sensor System (CCSS), Power Generation Cum Management Section (PGMS), and Thruster Systems (TS) are shown in Fig. 2.

The CCSS comprises of control computer with control algorithms, environmental, and vessel attitude sensors. The PGMS comprises of electric power generators (diesel prime movers and alternators), protection switchgears, bus bars, bus couplers, and intelligent power management systems (PMS). Based on the input command received from the CCSS, the PGMS dispatches the required power to the TS comprising of variable frequency drive-fed (VFD-fed) 3-phase electric motors for operating the azimuth and the tunnel thruster propellers. Depending on the vessel capacity, the installed power generation capacity in the PGMS varies from few hundreds of kilowatts to few tens of megawatts and propulsion thruster capacities vary up to a few megawatts.

Reliability is the key requirement for DP systems to ensure safe and successful completion of critical offshore operations. According to International Maritime Contractors Association (IMCA) database with 71 DP-related incidents reported from 54 vessels during 2014, 54% of the failures were due to technical failures in the DP system and the rest were due to human error, procedural and environment-related [14]. Taking into consideration the increasing number of DP vessels and the demand on risk reduction with increased HSE regulations; IMO and CS insist fault-tolerant DP systems using redundant architectures [7,8]. Hence, studies on reliability-centered DP system design based on the recently reported offshore component failure rates are inevitable to determine the trade off in redundancy, cost, weight and footprint. According to IMO guidelines, DP vessels are classified under Class 1, 2 and 3; and their requirements in terms of system operational availability are shown in Table 1.

## 3. Reliability determination methodology and data

Reliability is the capability of the system to perform its intended function during the defined period [15]. Failure rate of a component/subsystem is defined in Failure-In-Time (FIT), and represented as λ, expressed in failures per billion hours [16]. Given the number of failures and the total cumulative hours of operation, λ is calculated as represented in Eq. (2).

$$\lambda = (\text{No of failures} \times 10^9)/\text{Total operating time in hours} \quad (2)$$

From λ, the Mean Time To Fail (MTTF) is computed as,

$$\text{MTTF} = 1/\lambda \quad (3)$$

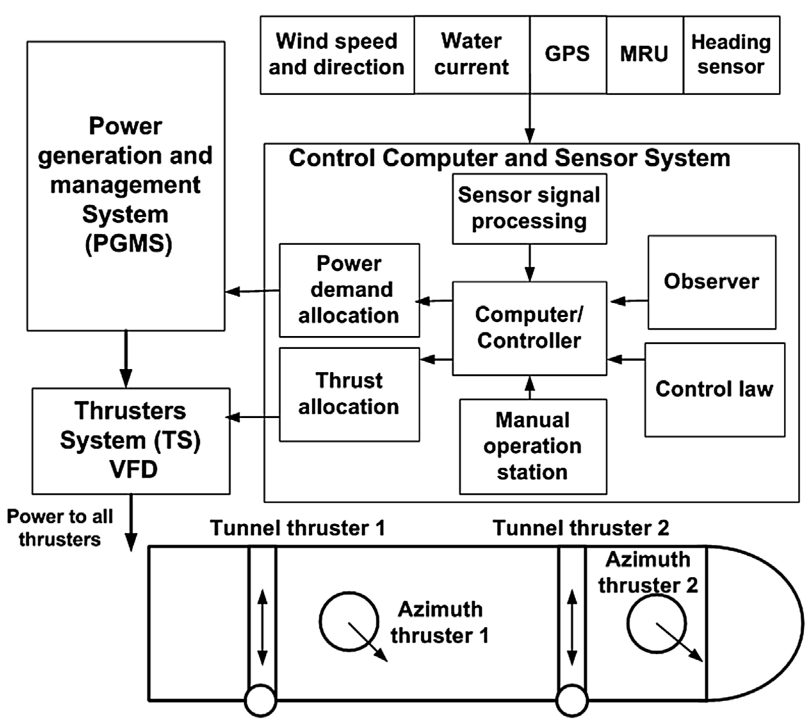


**Fig. 2.** Architecture of a typical vessel DP system.