MARINE TECHNOLOGY SOCIETY

DP VESSEL DESIGN PHILOSOPHY GUIDELINES

APPENDIX B

DP SHUTTLE TANKER REDUNDANCY CONCEPT PHILOSOPHY DOCUMENT

APRIL 2021

REVISIONS & CHANGES SUMMARY

Rev. No.	Date	Reason for Issue	Prepared by	Verified by	Approved by

Rev. No.	Section	Description of Changes

SUMMARY

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1 INTRODUCTION

1.1 OVERVIEW

1.1.1 The objective of this Redundancy Concept Philosophy Document (RCPD) is to communicate the redundancy concept and supplement the vessel's build specification in matters related to dynamic positioning. The intended audience for this RCPD includes all stakeholders involved with the design and build of the vessel including:

- Classification society
- Shipyard
- Equipment vendors
- 3rd party verifiers (FMEA supplier)
- Vessel Technical Operator's shore-based staff (Owner)
- Vessel crew

2 VESSEL INDUSTRIAL MISSION(S)

2.1 OVERVIEW

2.1.1 The vessel is to be a DP class 2 shuttle tanker carrying out crude oil offtake from FPSOs operating offshore Brazil.

3 VESSEL OVERVIEW

3.1 PRINCIPLE DIMENSIONS

3.1.1 The vessel has a conventional monohull tanker configuration with engine room, bridge and accommodation aft and cargo tanks forward. design outlined in this RCPD is a concept design for the purpose of obtaining Approval in Principle for DP Shuttle Tankers with a power plant arrangement based on autonomous thrusters and generators.

3.1.2 Table 3-1 provides details of the vessel's main particulars.

Table 3-1 Vessel Specification

Name	DPST - Concept	**Length O.A.**	285.0m
Shipyard	TBA	**Beam**	45.0m
Hull/Project No.	TBA	**Design Draught**	18 m
Construction	TBS	**Dead Weight**	150000 tonnes
Owner	TBA	**Speed Max.**	16.0 knots

3.2 DP RELATED EQUIPMENT AND SYSTEMS

3.2.1 The DP system's five independent equipment groups and thruster arrangement are shown in Figure 3-1. Figure 3-2 provides an overview of the power distribution system. The main features of this design include:

- A main engine driving a single controllable pitch propeller with rudder located at the stern. The propeller and rudder are integral to the DP capability of the DPST.
- A 6kV diesel electric power plant consisting of four diesel generators on four switchboard bus sections, provides power for the thrusters and all auxiliary systems (including those of the main engine, controllable pitch propeller and the steering gear).

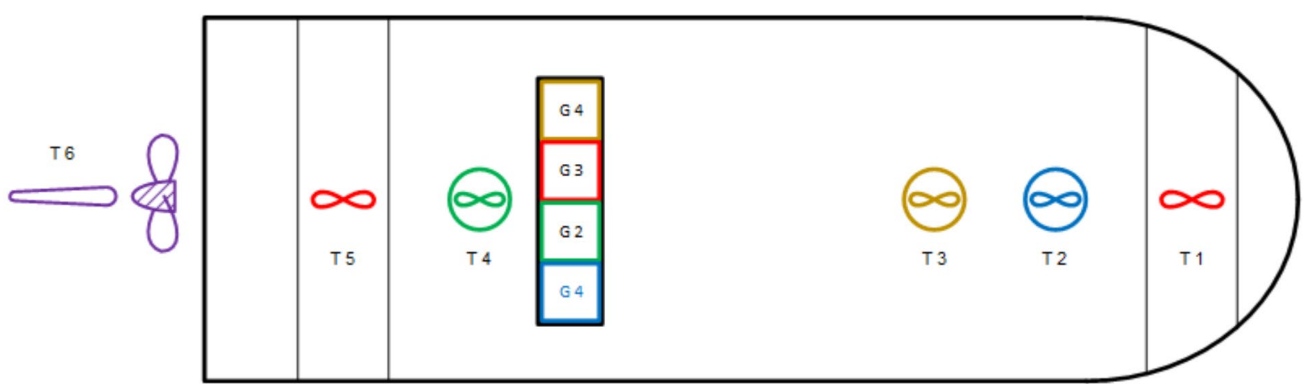


Figure 3-1 Independent DP Equipment Groups

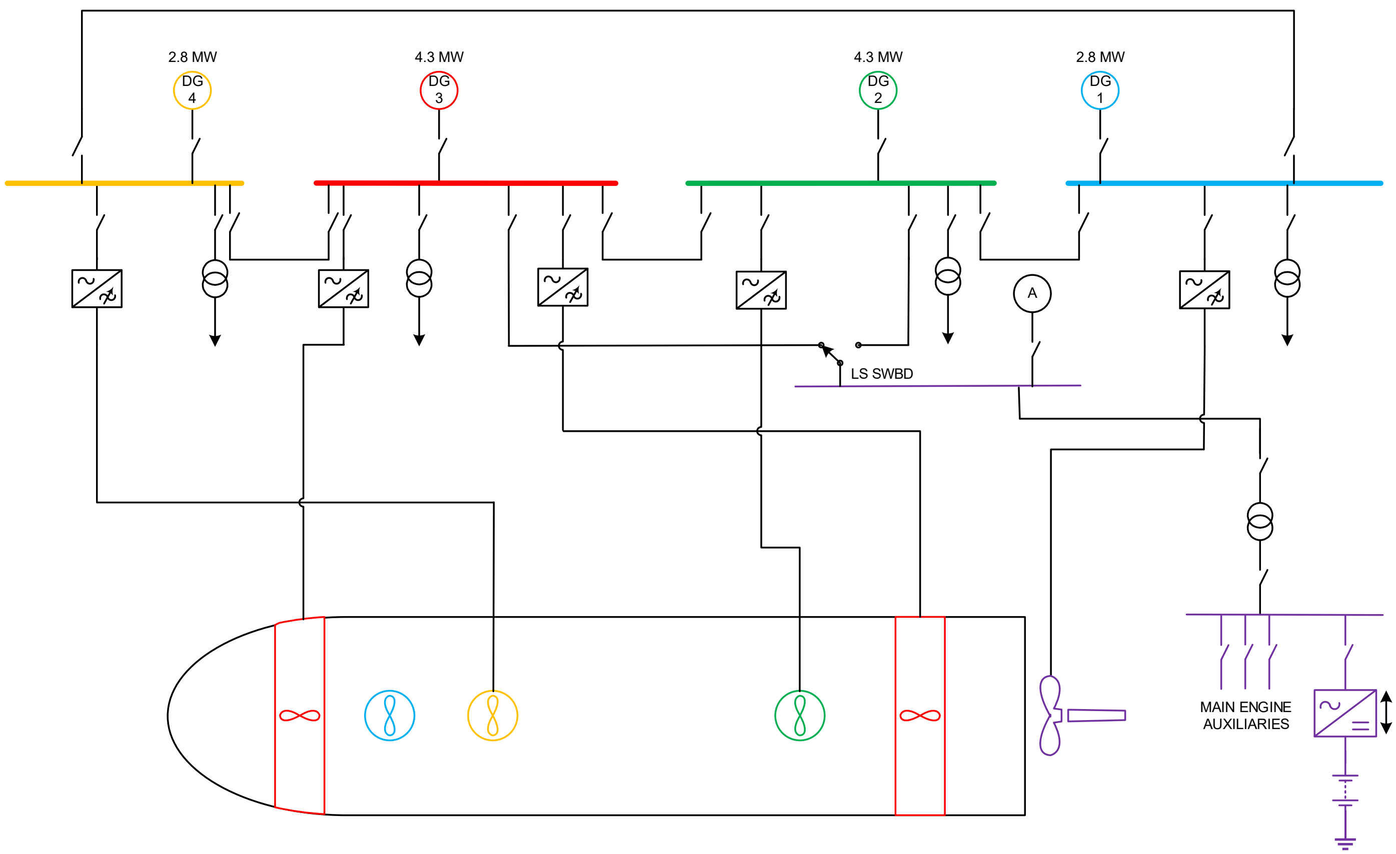


Figure 3-2 Redundancy Design Intent – (5 – Groups)

Table 3-2and Table 3-3 provide details of the generators, thrusters and main propulsion.

Table 3-2 Generators

Generator No.	Description	Red. Group	Power MW	Voltage	Frequency
G4	Port Outer	D	2.8	6kV	60Hz
G3	Port Inner	C	4.3		
G2	Stbd Inner	B	4.3		
G1	Stbd Outer	A	2.8		

Table 3-3 Thrusters

Thruster No.	Description	Red. Group	Power MW	Speed	Pitch
T1	Bow Tunnel Thruster	C	2.5	Variable	Fixed
T2	Bow Azimuth Thruster 1	A	2.5		
T3	Bow Azimuth Thruster 2	D	2.5		
T4	Stern Azimuth Thruster	B	2.5		
T5	Stern Tunnel Thruster	C	2.5		
T6	Main Propeller	E	16	Fixed	Variable
	Rudder	E			

4 CLASSIFICATION / EQUIPMENT CLASS

4.1 RULES

4.1.1 The vessel's DP system is to be built to DNVGL rules for rules for Dynpos AUTR. The vessel will have the following class notation:

+1A, Tanker for oil ESP, CSR, E0, DYNPOS(AUTR), BOW LOADING, TMON, NAUT(OC), BIS BWM(T), SPM, VCS(2), COAT-PSPC(B,C), RECYCLABLE, LCS, CMON, CLEAN, ER (SCR, Tier III)

The design of the vessel's DP system will comply with IMO MSC 1580 'Guidelines for Vessels and Units with Dynamic Positioning Systems. The DP systems consists of five equipment groups which can be considered to be independent in respect of common causes of failures when the failure criteria for Dynpos AUTR are applied.

5 DP SYSTEM OPERATING CONFIGURATIONS

5.1 GENERAL

5.1.1 The DP system will be designed to operate in the following configurations:

- Common power system - Closed Ring
- Any combination of 2 to 4 independent power systems - Open Busties

6 CODES, STANDARDS AND GUIDANCE

- Common Structural Rules for Double Hull Oil Tankers, July 2012
- DNVGL rules for Ships (RU-SHIP 2020)

7 OWNER'S/END USER-CHARTERER'S REQUIREMENTS

- Shell specification for DPST
- MTS DP Design Philosophy Guidelines
- MTS TECHOPs

8 REDUNDANCY DESIGN INTENT(S) & WORST-CASE FAILURE DESIGN INTENT(S)

8.1 DP SYSTEM REDUNDANCY DESIGN INTENT

8.1.1 The DP System's redundancy design intent, in Table 8-1, describes the effects of losing any one of the independent equipment groups. It is based on five independent equipment groups. The thrusters and generators are colour coded as indicated in Figure 3-1 and Figure 3-2.

Table 8-1 Redundancy Design Intent

Failure Status	Thrusters Available	Redundancy Type
Intact	T1 T2 T3 T4 T5 T6	Active
Failure of A	T1 T3 T4 T5 T6	None
Failure of B	T1 T2 T3 T5 T6	None
Failure of C	T2 T3 T4 T6	None
Failure of D	T1 T2 T4 T5 T6	None
Failure of E	T1 T2 T3 T4 T5	None

8.2 LIFE CONCEPT

8.2.1 The LIFE concept was developed by applying the principle autonomy, independence and segregation. The LIFE concept also utilises the principle of critical and non-critical redundancy to increase the reliability of each independent DP equipment group. The terms are defined as follows:

- The loss of critical redundancy will impact the vessel's post failure DP capability.
- Non-critical redundancy has no effect on post failure DP capability but improves the reliability and maintainability of the independent or redundant DP equipment group to which it is applied.

8.2.2 In newbuild LIFE Concept designs the Worst Case Failure Design Intent (WCFDI) does not consider the possibly of faults acting directly on the HV bus bars – This exemption is only valid when the switchboards have been specifically designed to be short circuit proof – Thus the WCFDI for Dynpos AUTRO may differ from that defined for LIFE concept Two WCFDIs will be maintained throughout the vessel's operational life.

8.3 MARINE SYSTEMS

8.3.1 In the case of marine auxiliary systems this involves providing two 100% duty /standby pump pairs and two 100 heat exchangers. The pumps power supplies both originate within the same independent equipment group. The philosophy of proving dual pumps is to be able to tolerate failure of a pump and not failure of its power supply. However, the two pump supplies are arranged from separate distribution board providing a degree of resilience to local power supply failure.

8.3.2 In the case of control power supplies, additional 24Vdc power supplies or additional UPS all within the same indecent equipment group.

8.4 WORST CASE FAILURE DESIGN INTENT – DYNPOS AUTR

8.4.1 The vessel’s worst-case failure design intent is derived from the Redundancy Design Intent and is defined as follows:

‘No single failure as defined for DNVGL notation Dynpos AUTR will have a greater effect on the vessel’s ability to maintain position and heading than the loss of independent group C.’

- This intent applies in all defined power plant configurations.
- For this intent to be valid, all equipment must be capable of its defined performance and all protective functions must operate successfully on demand.

8.5 WORST CASE FAILURE DESIGN INTENT – LIFE CONCEPT

8.5.1 The vessel’s worst-case failure design intent is derived from the Redundancy Design Intent and is defined as follows:

No single failure as defined for LIFE Concept will have a greater effect on the vessel’s ability to maintain position and heading than the loss of one generator or one thruster.

- This intent applies in all defined power plant configurations.
- For this intent to be valid, all equipment must be capable of its defined performance and all protective functions must operate successfully on demand.
- WCFDI for LIFE concept on a DP Class 2 Vessel does not consider the possibility of a faut acting directly on the main switchboard bus bars.

9 EXPECTATIONS FOR VERIFICATION AND VALIDATION

9.1 INTENTION TO VALIDATE

9.1.1 The following tests will be carried out whether or not they are required by Dynpos (AUTR):

- All compensating provisions used to address common points will be tested for effectiveness. In particular:
  - Protective functions (electronic, electrical and mechanical)
  - Automatic changeovers
  - Diode isolation of dual supplies
  - Standby redundancy
- Short circuit and ground fault testing on all power distribution systems where cross connections exist.
- Network storm and throughput testing on data communication networks.
- All DP system components will be tested to prove their performance.

Note: In the absence of instructions in the vessel owner's specification, the shipyard will take owner's instruction on what verification and validation testing is required.

Thus, testing may be required even if:

- It is not specified in the rules for the DP notation.
- It is not carried out as established custom and practice.

Often it is possible to make a technical argument for why such testing is actually required by the class rules.

10 CONCLUSIONS

10.1 OVERVIEW

10.1.1 The DP redundancy concept described in this RCPD is based on 5 independent DP equipment groups which rely for their fault tolerance on:

- A range of protective function designed to prevent faults propagating through closed busties.
- Stored energy assigned to keep the main engine auxiliary systems running.
- Exemption of certain mechanical components from consideration in the FMEA

APPENDICES

APPENDIX 1. SYSTEM SKETCHES

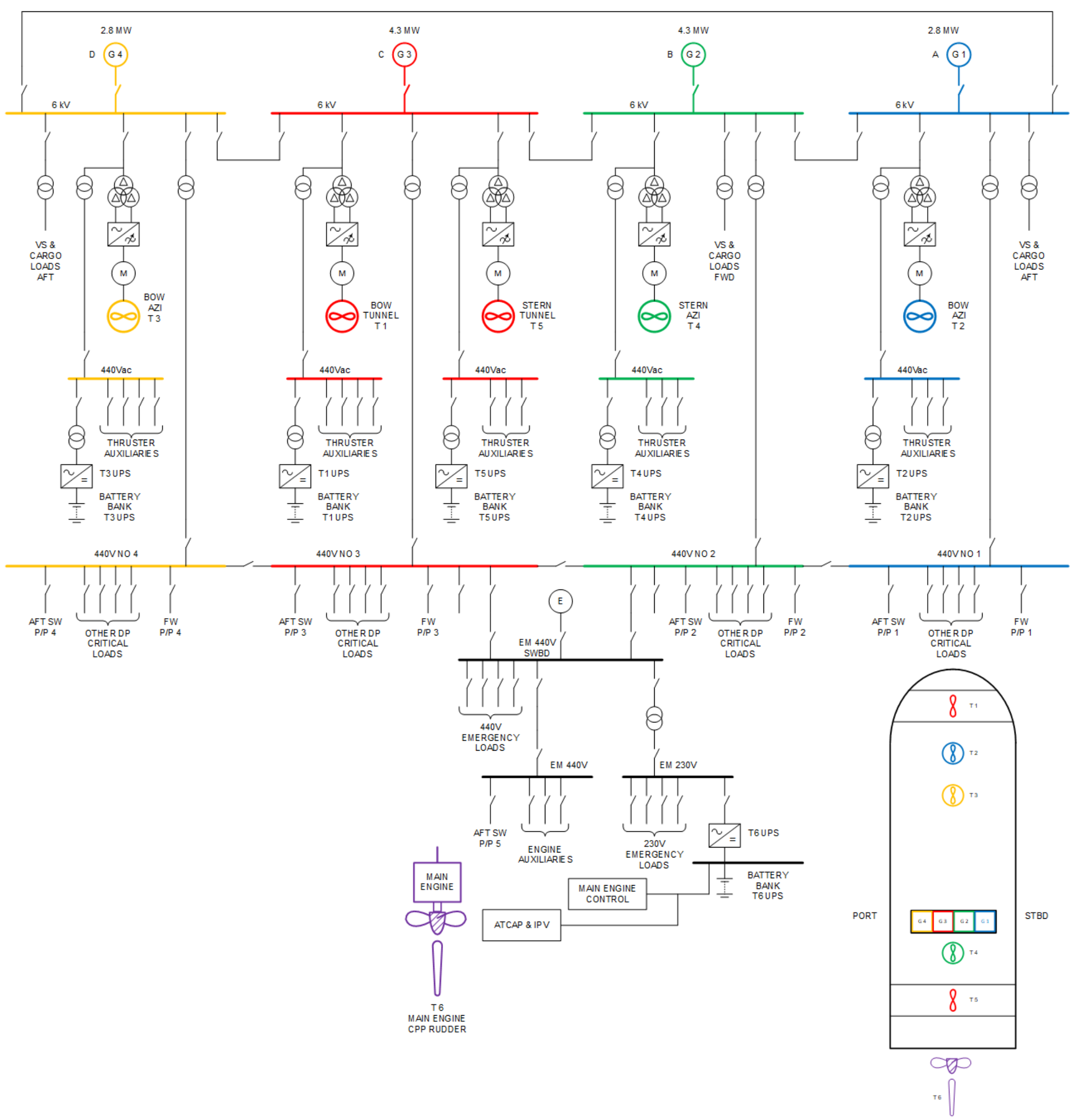
A1.1. INTRODUCTION

A1.1.1. The section which follows provided sketches which illustrate how the redundancy design intent is implemented on a system by system basis.

A1.2. POWER GENERATION AND DISTRIBUTION

A1.2.1. The Redundancy Concept is most readily visible in design of the Power Generation and Distribution systems which consists of four autonomous 6kV power systems and a LV power system for the Main Engine auxiliaries featuring a Battery Energy Storage System (BESS).

A1.2.2. Each power systems powers a single thruster with the exception of System C which powers the two tunnel thrusters.



Appendix 1 - Figure 1 Power Distribution System

A1.3. AUTONOMOUS GENERATORS AND THRUSTERS

A1.3.1. All power for the thrusters is derived from the HV feeder. A step-down distribution transformer supplies the thrusters' auxiliaries. Each generator has a dedicated MCC suppling power to its auxiliary systems. Power for this MCC is reduce form the appropriate section of the 440V bus.

A1.3.2. Autonomous designs lend themselves to the development of compact self-contained generators and thrusters which are modular in nature. This has the effects of:

- Creating well defined and easily understood system boundaries.
- Minimising the interface to other systems
- Minimising the number of potential fault propagation paths
- Reducing the opportunity for configuration errors
- Minimising the number of integration issues
- Maximizing the opportunity for pre-assembly, pre-commissioning and testing at an advanced stage of completion
- Reducing the verification and validation burden and simplifying the FMEA process
- Reducing the periodic reverification burden

A1.4. TREATMENT OF THE MAIN ENGINE

A1.4.1. DP shuttle tankers will typically have a large slow speed main engine for use during transit. From a DP perspective the main engine, CPP and rudder are treated as a transferable engine driven thruster which is intended to be independent in so far as it should only ever fail on its own and not with any other thruster.

A1.4.2. Difficulties in creating a truly autonomous design arise when the main engine has no dedicated independent source of electric power. In such design the main engine power is supplied from the main power generations system by way of duals supplies, auto changeover over or duty-standby pump arrangements. All these methods introduced potential fault propagation paths or increase exposure to hidden failures. They also add to the initial verification and reverification burden.

A1.4.3. In this design there are four sources of supply for the main engine auxiliary systems as follows:

- Redundancy Group C – Main supply
- Redundancy Group D – Backup supply by way of smart fail-safe auto changeover
- An auxiliary generator
- A battery energy storage system of limited capacity

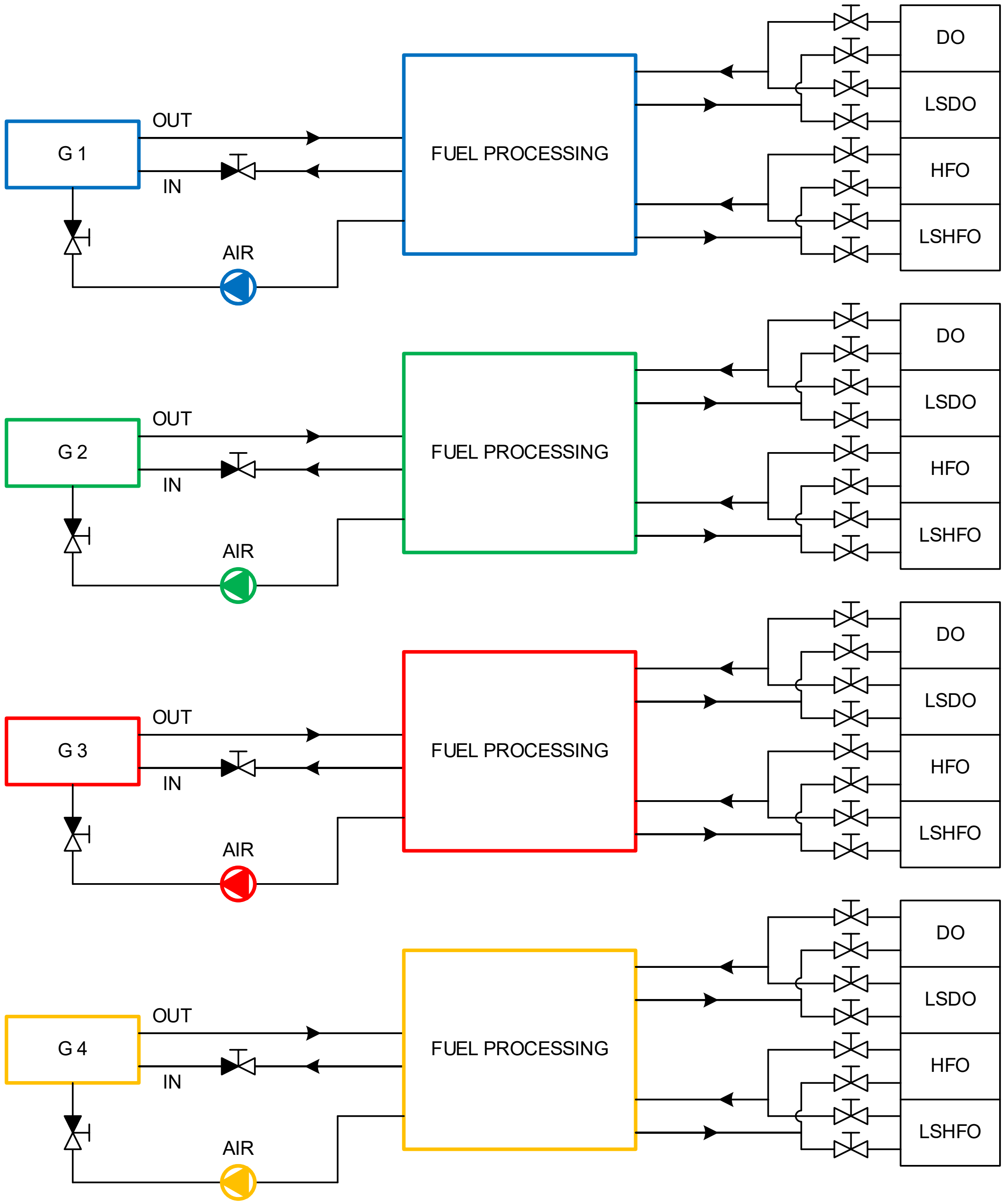
Note: *In this case the auxiliary generator could potentially be the Emergency Generator (Subject to classification Society approval)*

- A dedicated auxiliary generator
- A shaft generator driven from the main engine.

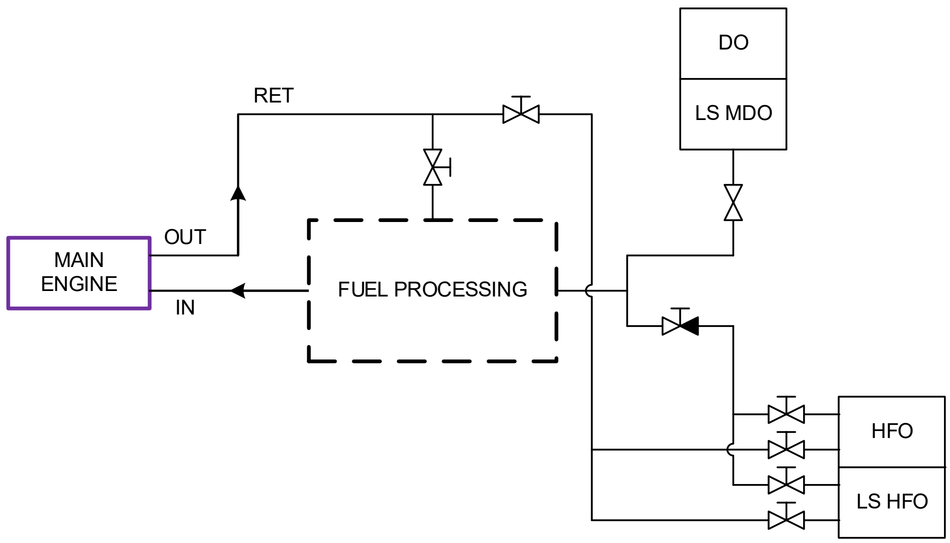
A1.4.4. Use of the emergency generator as part of the main engine redundancy concept might be possible, in some class notations, but not in others. Where it is not allowed by the rules, it may be necessary to provide a dedicated generator for the main engine. A shaft generator is another possibility.

A1.5. FUEL SYSTEM

A1.5.1. Appendix 1 - Figure 1 and Appendix 1 - Figure 2 show a fully segregated fuel system capable of maintaining segregation of four different grades of fuel.



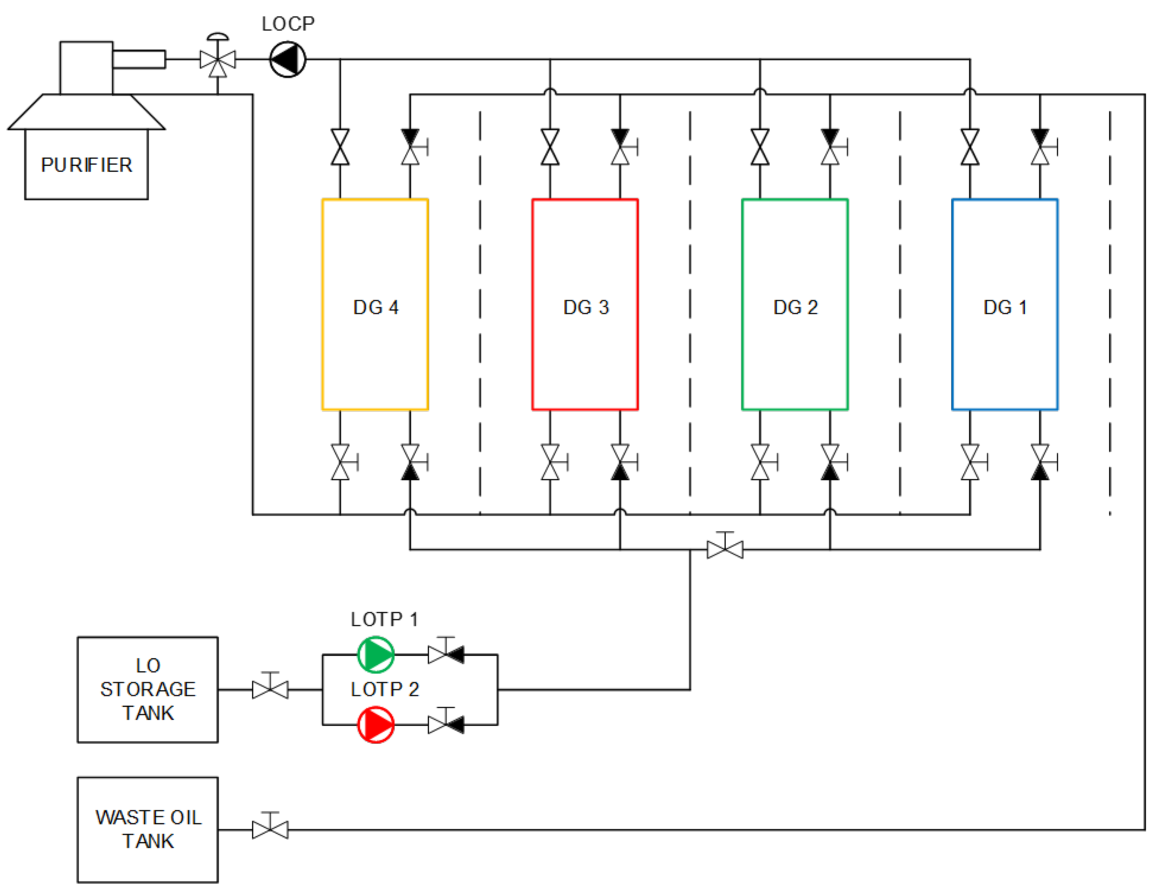
Appendix 1 - Figure 2 Fuel System



Appendix 1 - Figure 3 Main Engine Fuel System

A1.6. LUBRICATING OIL SYSTEM

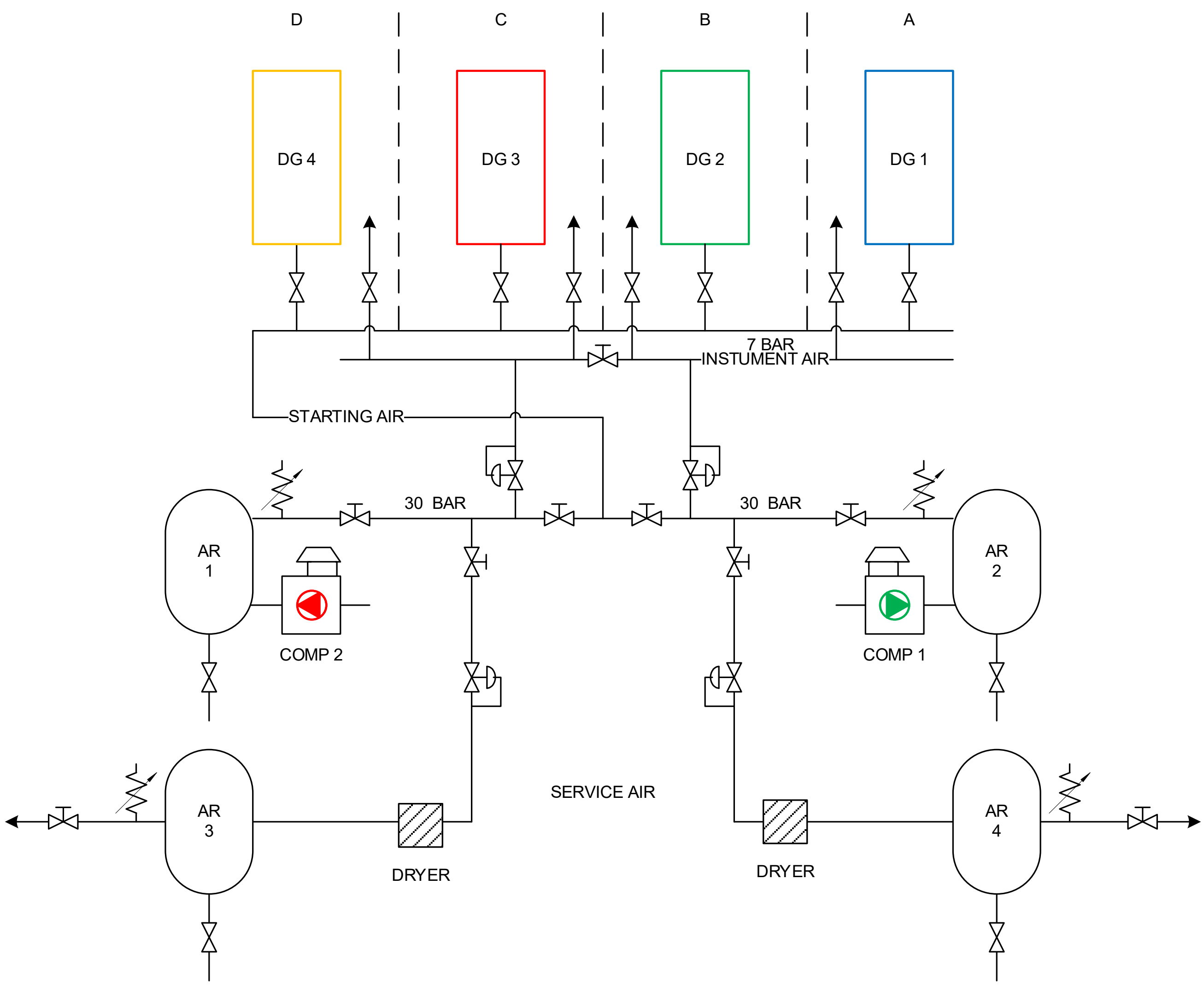
A1.6.1. Appendix 1 - Figure 4 shows the Lubricating Oil transfer and purification system is common to all four diesel generators. Procedures and oil sampling are used to mitigate the effects of the commonality so introduced.



Appendix 1 - Figure 4 Lubricating Oil System

A1.7. COMPRESSED AIR SYSTEMS

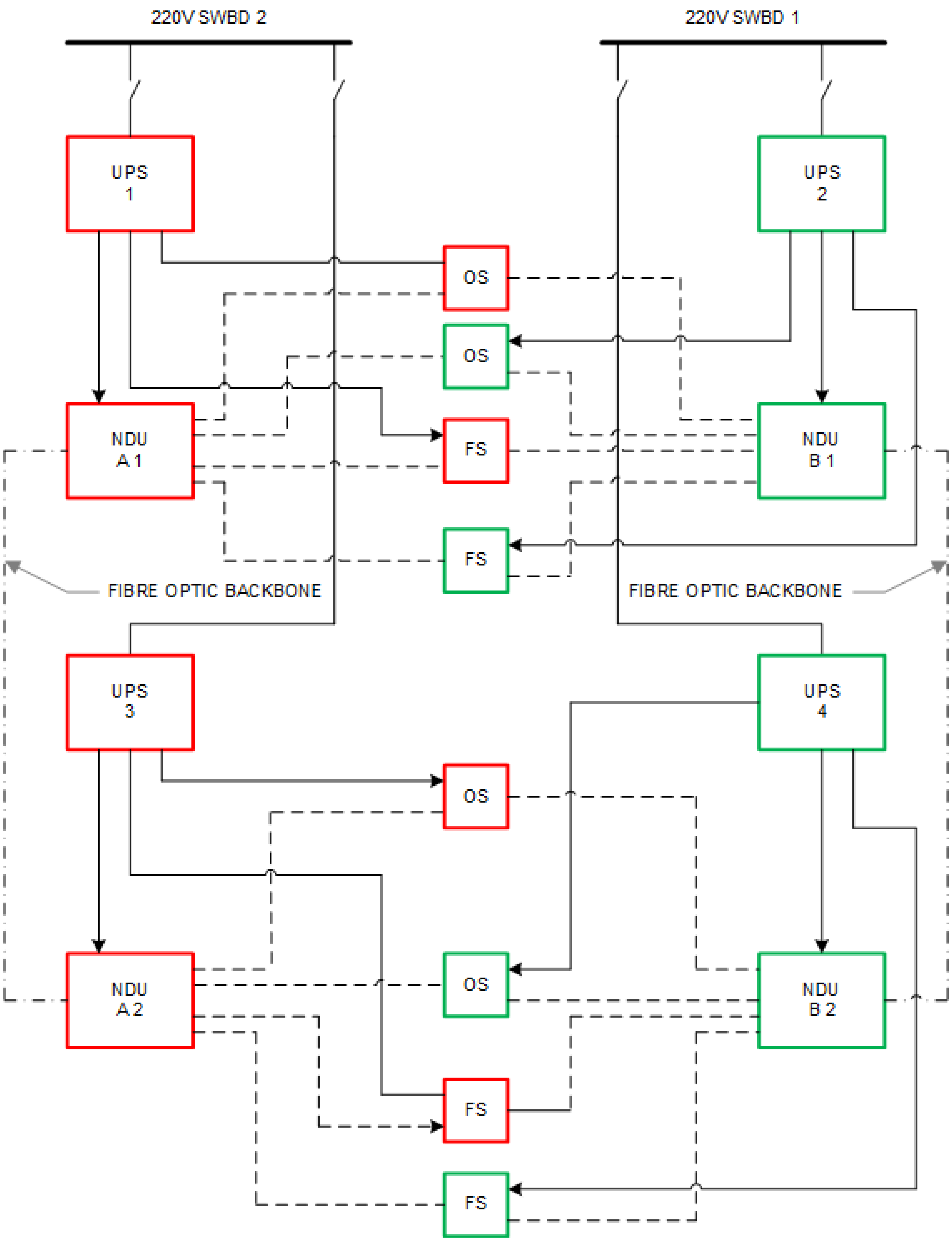
A1.7.1. Appendix 1 - Figure 5 shows the compressed air systems are common to all four diesel generators. The commonality so introduced is mitigate by the fail-safe nature of the equipment served by the compressed air systems. Engines and thrusters all continue to operate without compressed air. Risks associated with overpressure are mitigated by pressure relief valves.



Appendix 1 - Figure 5 Compressed Air System

A1.8. DATA COMMUNICATION NETWORKS

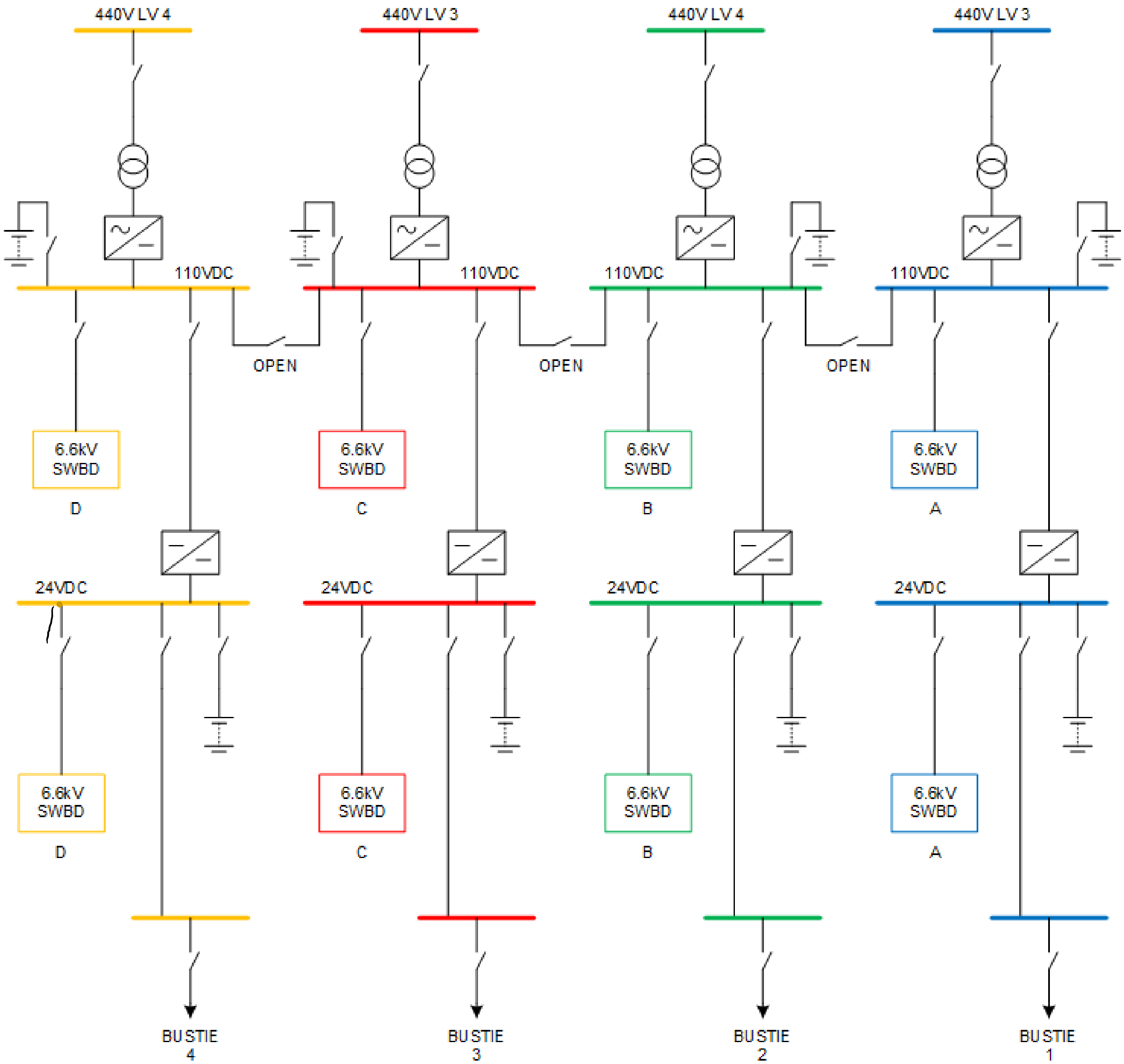
A1.8.1. Appendix 1 - Figure 6 shows the data communication networks. are arranged as a dual redundant data highway. A dual-star type arrangement is used with Network Distribution Units connected by a Fibre Optic backbone. Every field station and operators station form a common point between the A Network and the B network, and each network is connected to every data consumer / producer in the DP System. Verification and validation testing will include Network Storm testing to prove the protection against common mode failures is effective. Performance testing will be carried out to prove both networks are capable of their rated performance.



Appendix 1 - Figure 6 **Data communication Networks**

A1.9. 110VDC & 24VDC CONTROL POWER

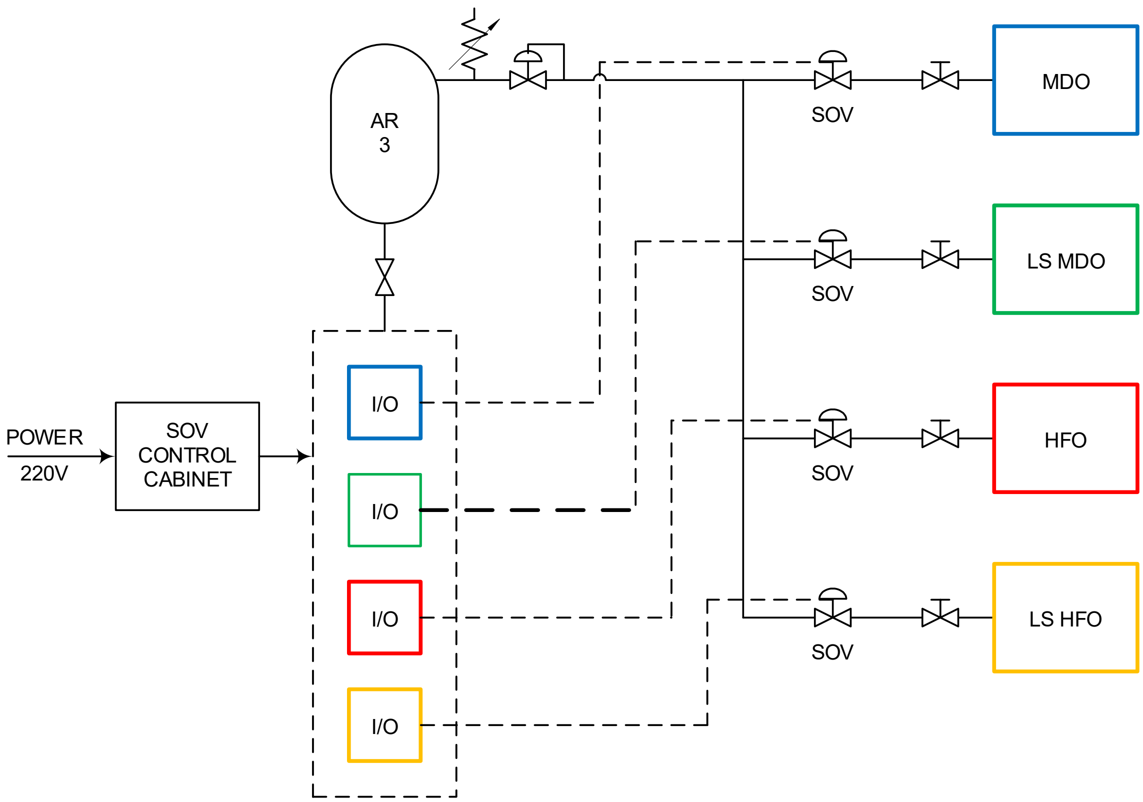
A1.9.1. Appendix 1 - Figure 7 shows a fully segregated control power supply system. Additional robustness has been added by provide the 24Vdc section with its own stored energy.



Appendix 1 - Figure 7 110Vdc and 24Vdc Control Power

A1.10. REMOTE CONTROLLED VALVES

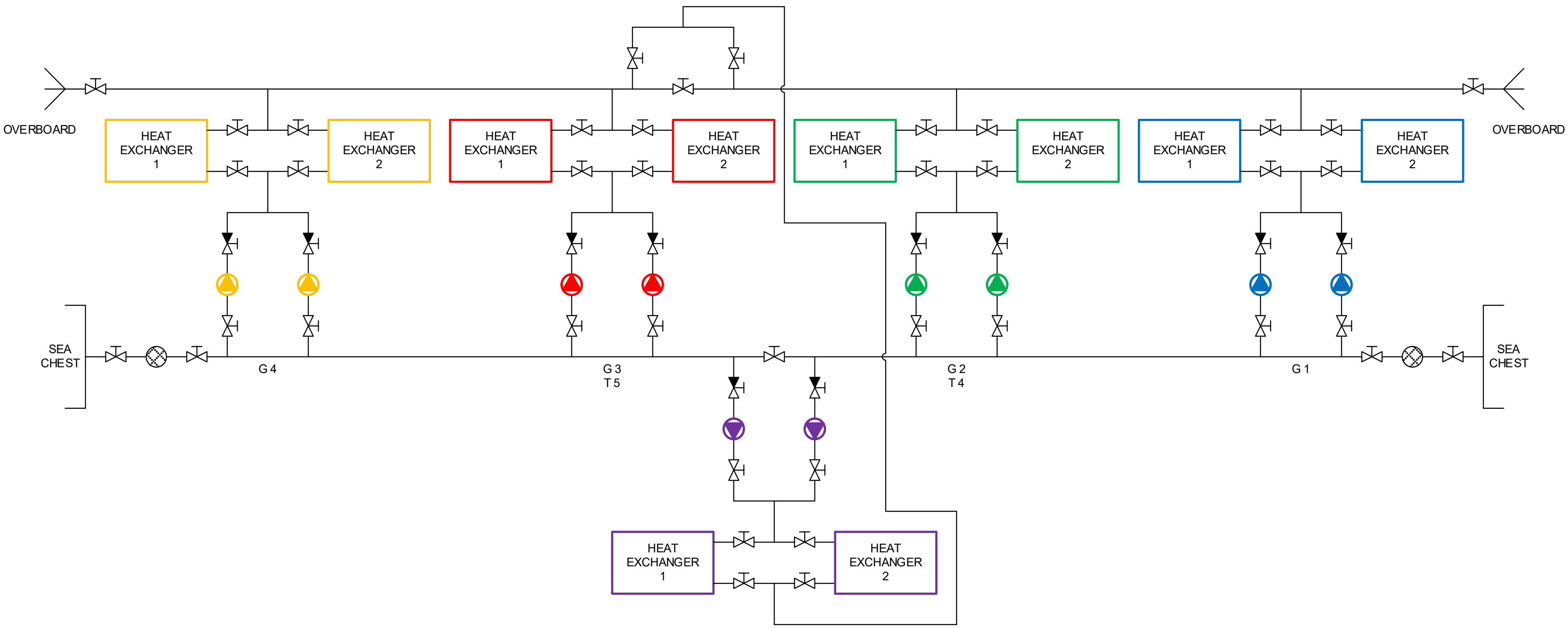
A1.10.1. Appendix 1 - Figure 8 shows a revised system for the fuel system QCVs. In this design the common air supply has been proven to be acceptable because of the fail-safe nature of the valves on loss of air pressure. The risk of a single point failure within the control cabinet commanding all the valves to close has been addressed by ensuring that valves for more than one independent DP equipment group are not located on the same I/O card.



Appendix 1 - Figure 8 QCV Control Power and signal

A1.11. MAIN SEAWATER COOLING SYSTEM

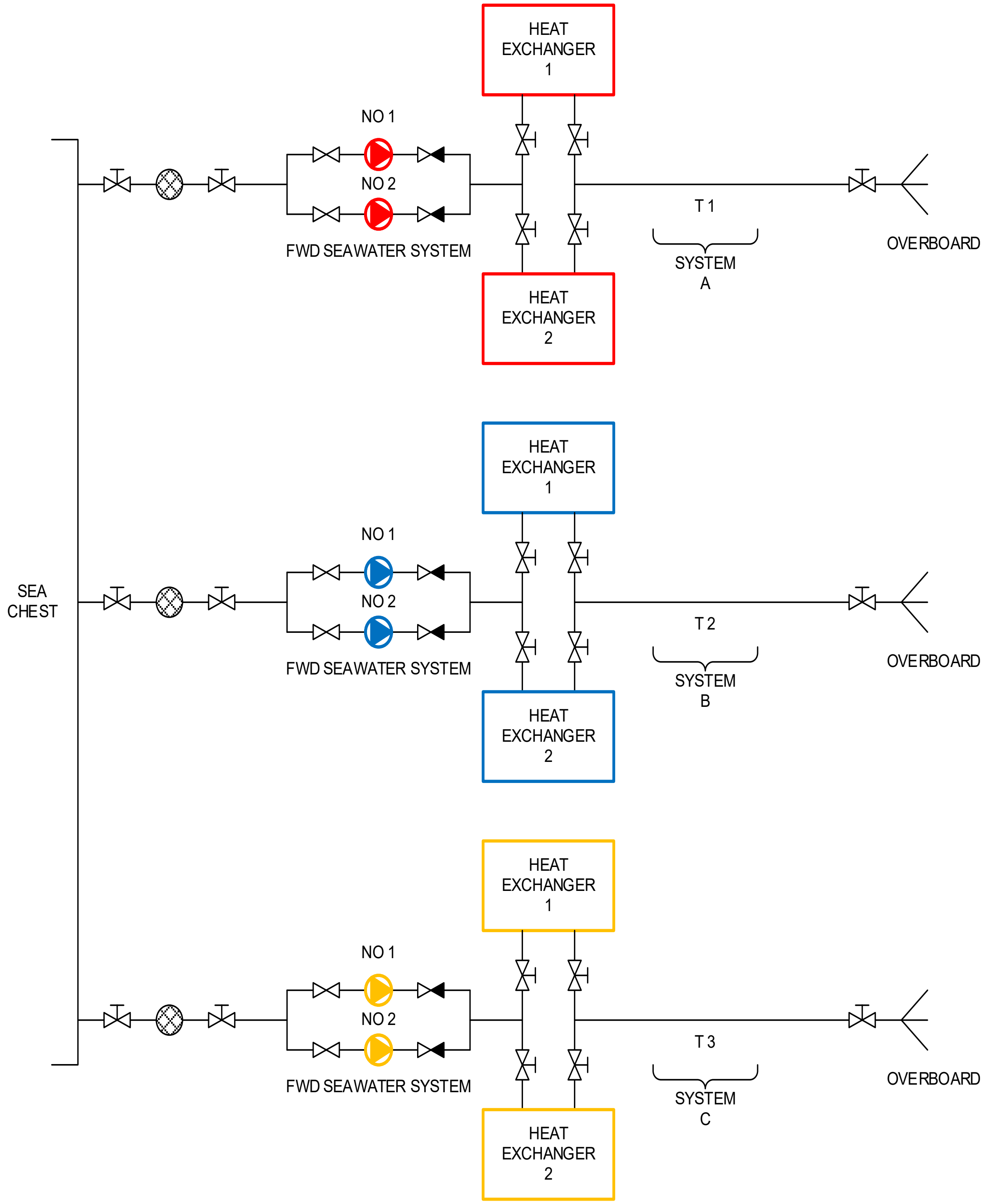
A1.11.1. Appendix 1 - Figure 9 shows the main seawater cooling system. Some commonality exists in this design as it is accepted that the risks of pipework failure in a seawater system lower and there is typically a substernal time lag before the effect of failure is felt in the freshwater cooled systems. The system has redundancy in overboard discharge and the ability to segregate a faulty section. It also provides for dedicated duty standby pumps and heat exchangers removing reliance on active elements and exposure to hidden failure.



Appendix 1 - Figure 9 Main Seawater Cooling System - Aft

A1.12. FORWARD SEAWATER SYSTEM

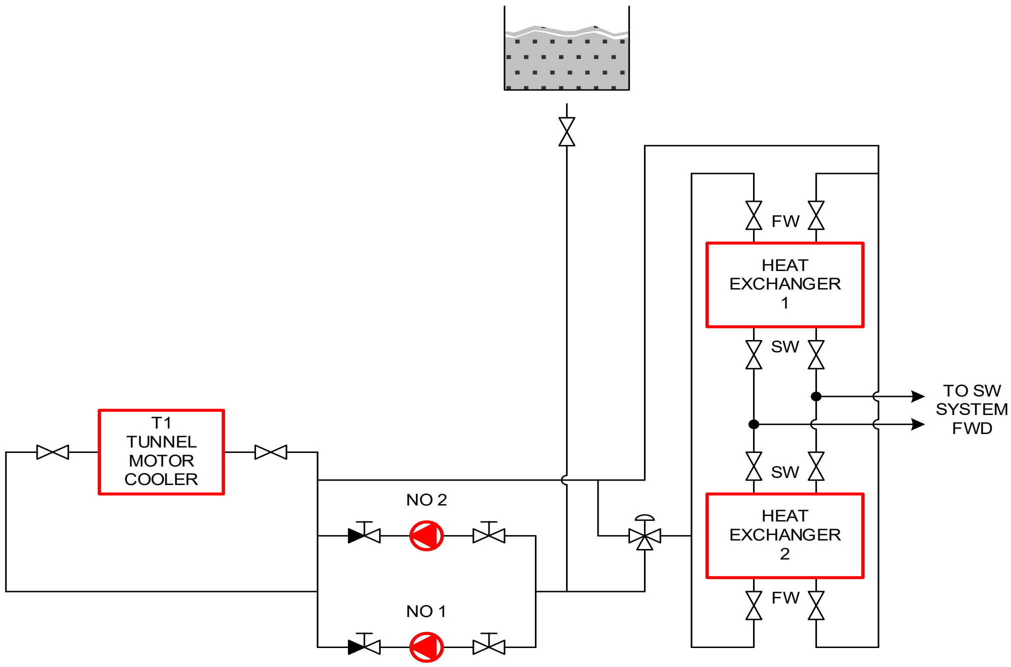
A1.12.1. Appendix 1 - Figure 10 shows the forward seawater cooling system. This design has full segregation and lends itself to a modular self-contained approach. As with the main seawater system, the use of non-critical redundancy is not essential but improves operability and maintainability.



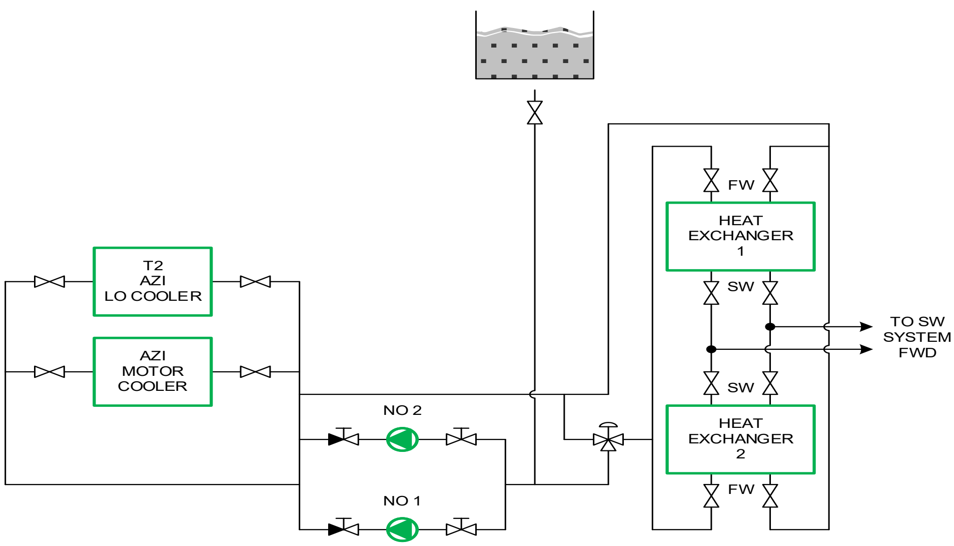
Appendix 1 - Figure 10 Main Seawater Cooling System - Fwd

A1.13. FORWARD FRESHWATER COOLING SYSTEM

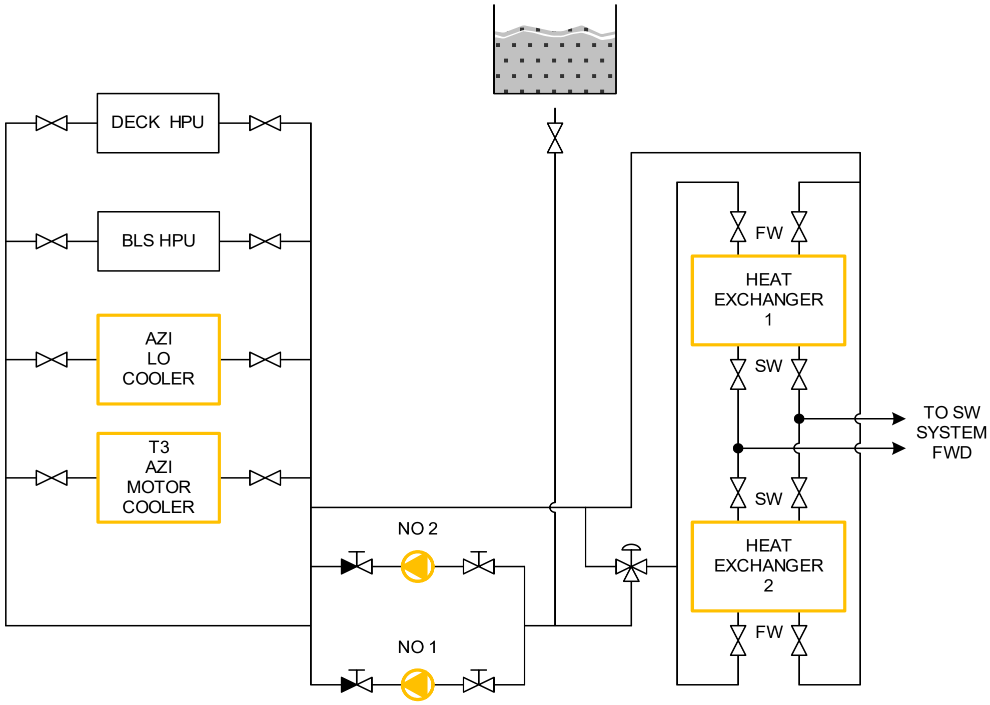
A1.13.1. Appendix 1 - Figure 11 to Appendix 1 - Figure 13, show the freshwater cooling system for the three forward thrusters, T1 T2 and T3.



Appendix 1 - Figure 11 Forward FW Cooling System T1



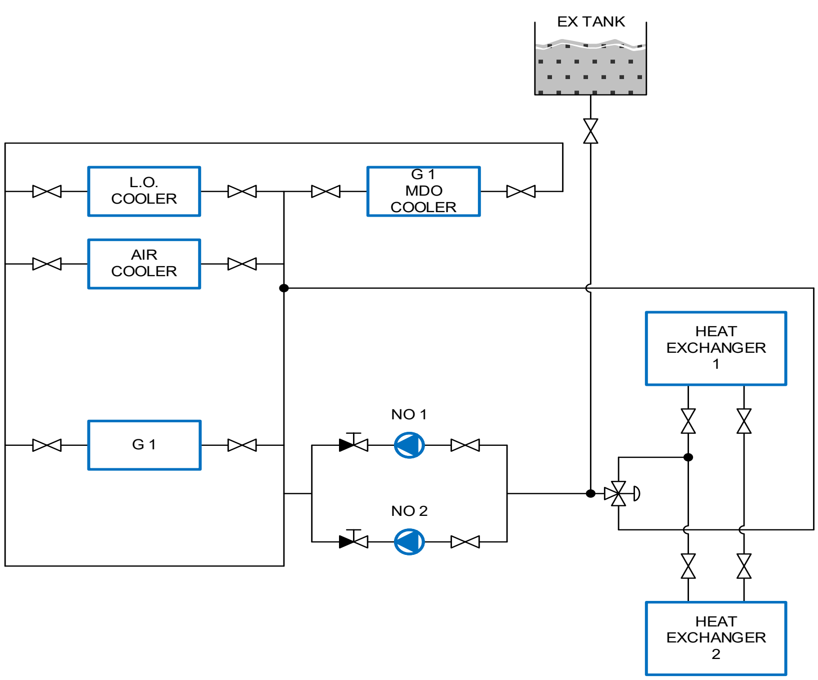
Appendix 1 - Figure 12 Forward FW Cooling System T2



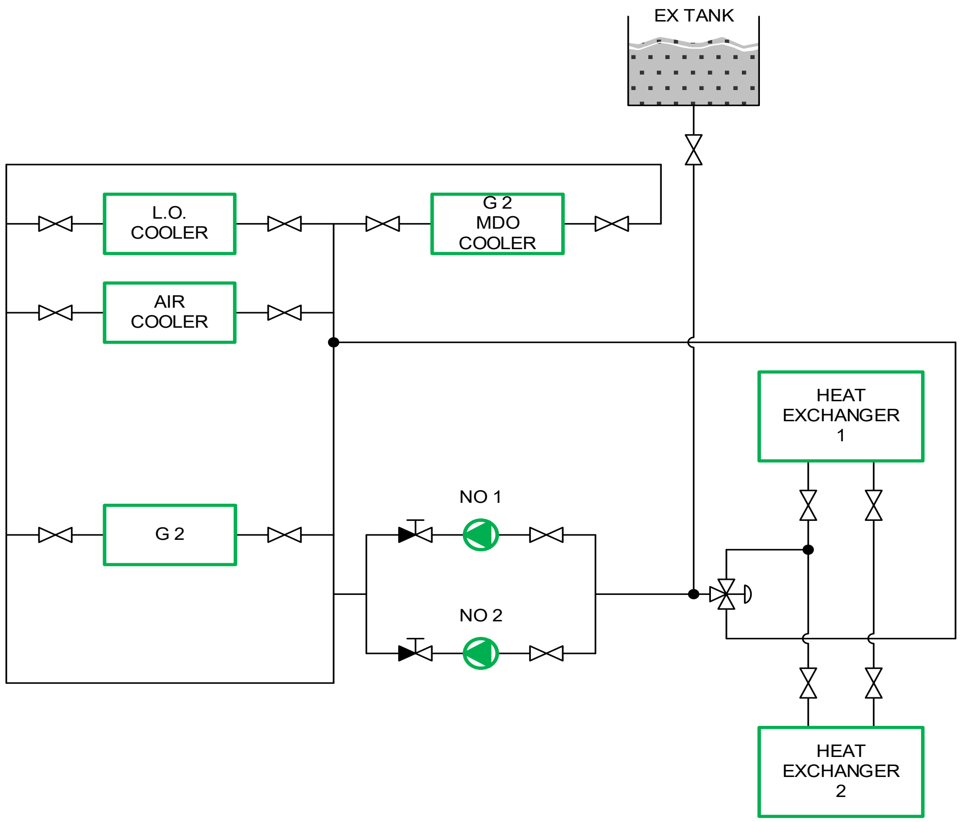
Appendix 1 - Figure 13 Forward FW Cooling System T3

A1.14. MAIN FRESHWATER COOLING SYSTEMS

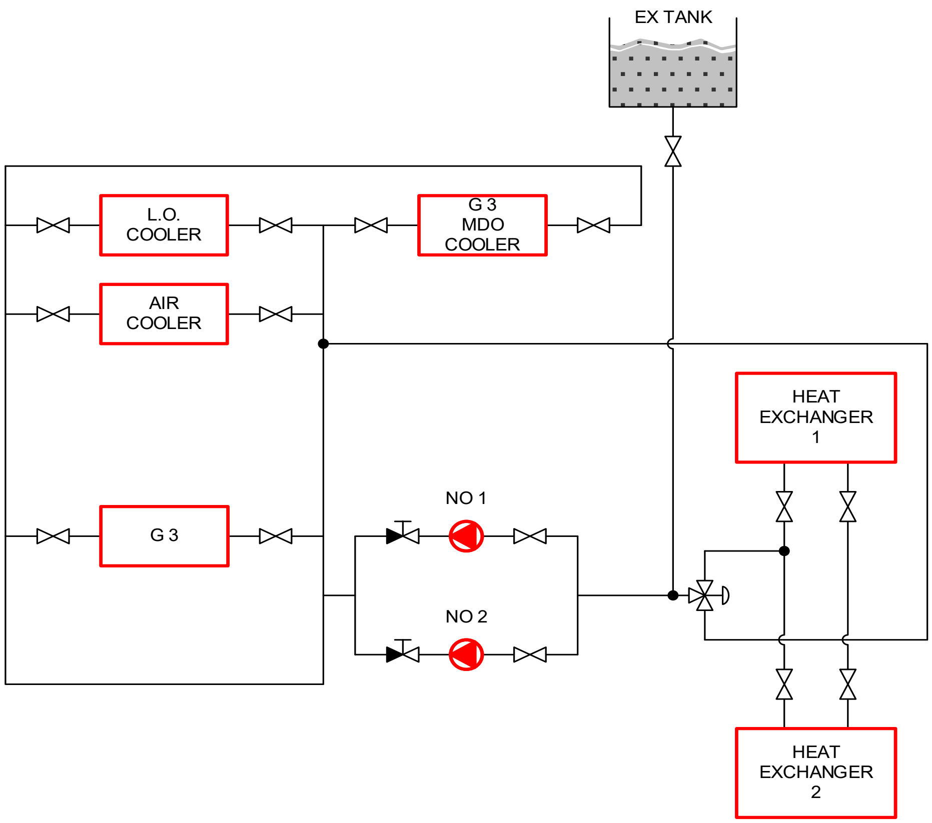
A1.14.1. Appendix 1 - Figure 14 shows the freshwater cooling systems for diesel generator G1. An identical design, based on segregation has been applied to the freshwater cooling system for all the main generators as shown in Appendix 1 - Figure 15, Appendix 1 - Figure 16, Appendix 1 - Figure 17.



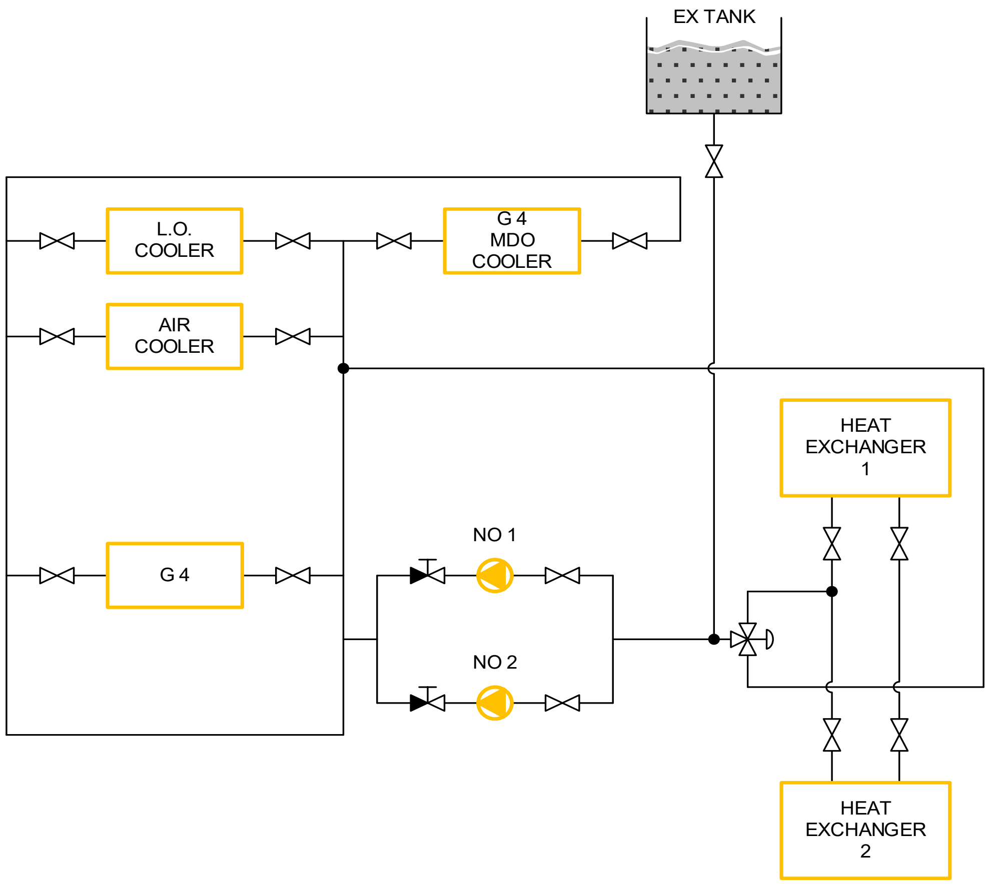
Appendix 1 - Figure 14 Freshwater Cooling System G1



Appendix 1 - Figure 15 Freshwater Cooling System G2



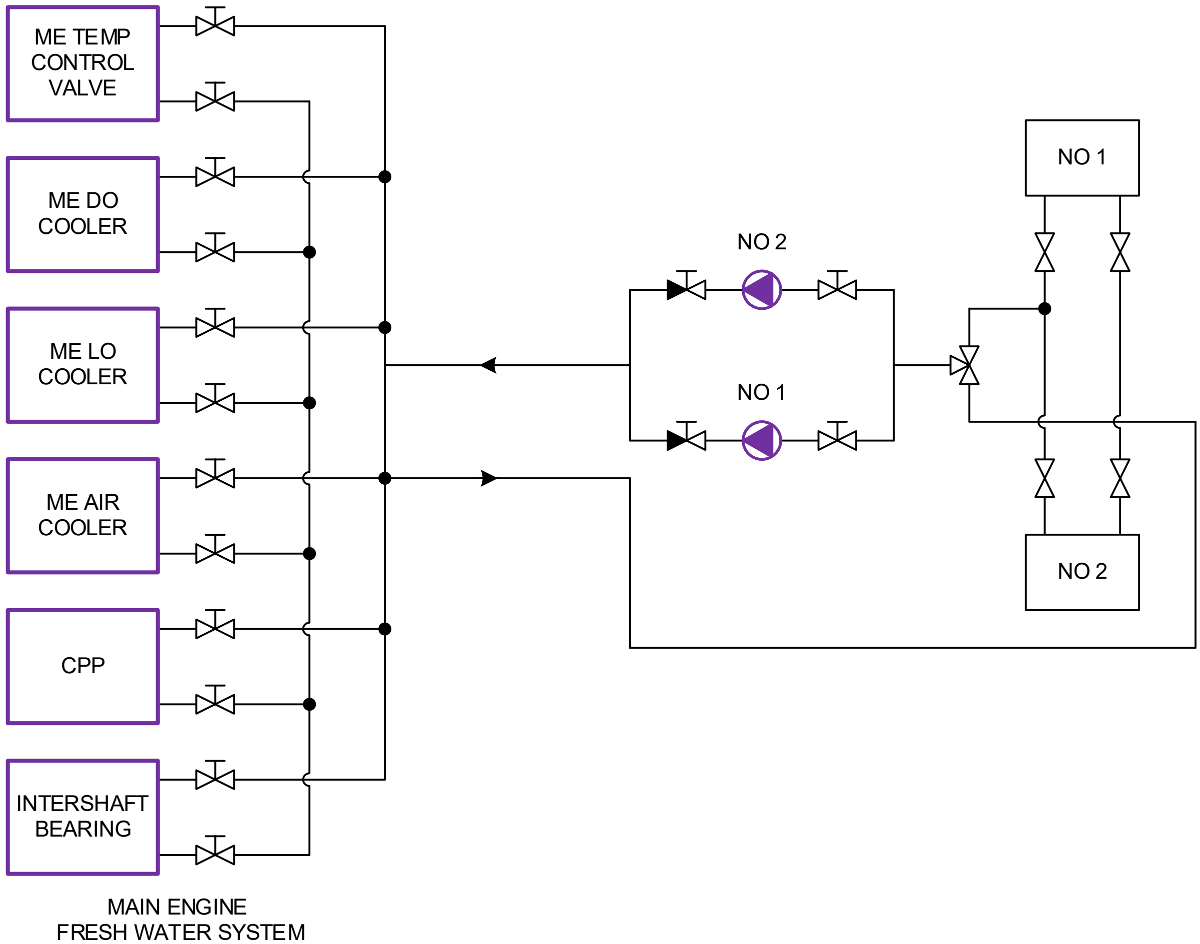
Appendix 1 - Figure 16 Freshwater Cooling System G3



Appendix 1 - Figure 17 Freshwater Cooling System G4

A1.15. MAIN ENGINE FRESHWATER COOLING SYSTEM

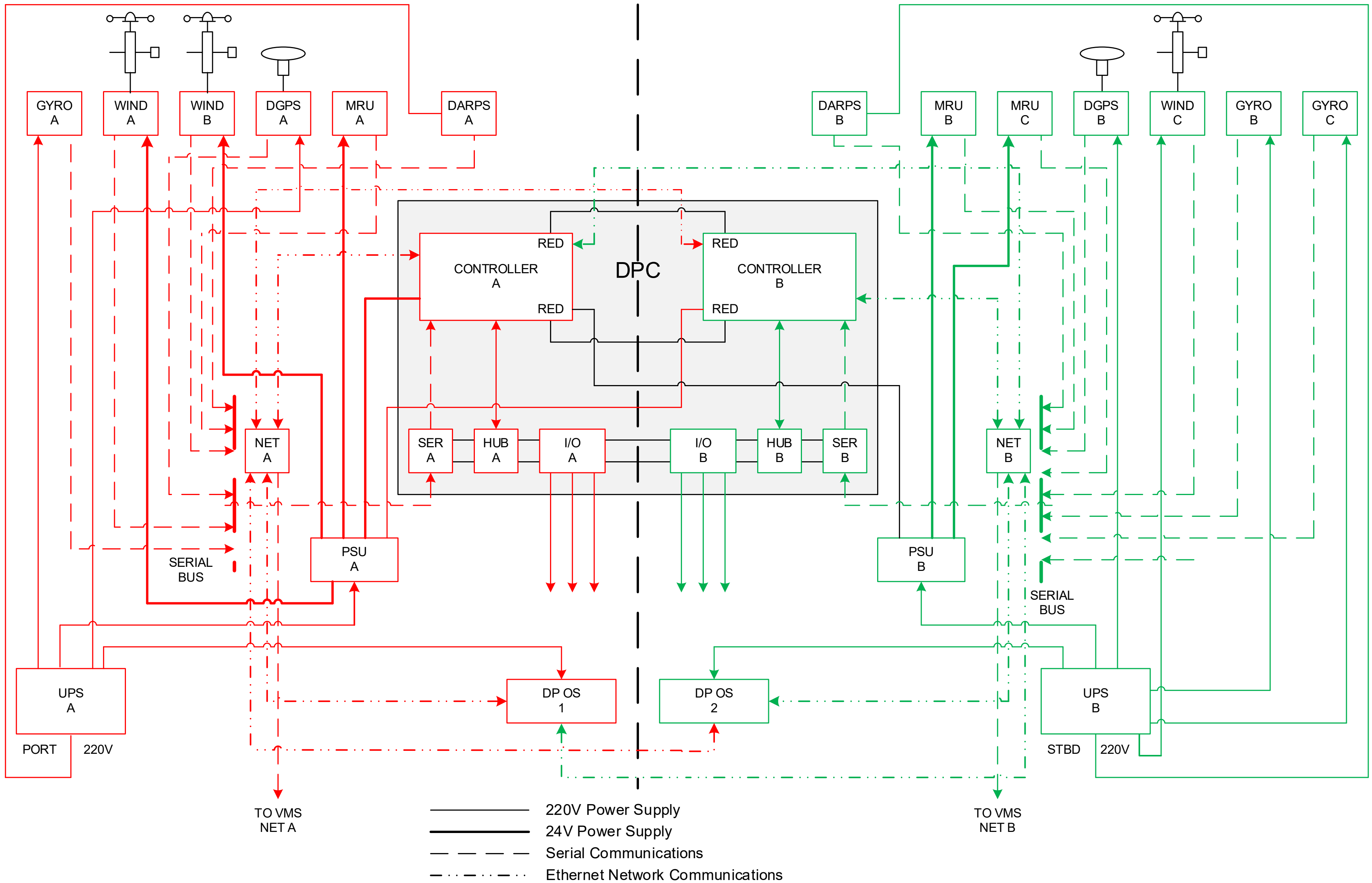
A1.15.1. The main engine cooling water system is independent as shown Appendix 1 - Figure 18.



Appendix 1 - Figure 18 ME Freshwater Cooling System

A1.16. DP CONTROL SYSTEMS

A1.16.1. Appendix 1 - Figure 19 shows the DP control system and its position references and sensors. Because standby redundancy is used to provide fault tolerance, a number of cross connections will be accepted in this system with the appropriate compensating provision to mitigate the risk of fault propagation. The rationale behind this is that the risk of a failed changeover to the standby controller is estimated to be higher than the risk from fault propagation (when properly mitigated).



Appendix 1 - Figure 19 DP Control Systems

APPENDIX 2. DIVERGENCE - LIST OF COMMON POINTS

A2.1. COMMONALITY IN MAJOR SYSTEMS

A2.1.1. The list of common points was extracted from the system sketches. There are no unmitigated common points other than seawater cooling system pipework which is considered to have a low risk of failure.

Colour Key	Meaning
(Green)	No Common Point
(Yellow)	Mitigated by Compensating Previsions
(Pink)	Unmitigated but Considered Low Risk

Appendix 2 - Table 1 List of Common Points in Example 1

System	Nature of Common Point
110Vdc & 24Vdc control power	None
Fuel Systems DG & ME	None
Emergency MDO fuel systems	None
Lubricating Oil systems	Limited commonality in supplies to Lube Oil Transfer Pump power supplies - No direct connection
G1 to G4 FW cooling	None
Main Engine FW cooling Systems	None
Forward Freshwater Cooling System	None
Main SW cooling system (inc. Main engine)	Common Sea suction for Port Generations, common Sea Suction for Starboard Generators
Forward Seawater Cooling System	Common Sea Suction
Compressed air systems	Common but fail safe
Remote Valve Operating System	Common software and controllers but independent I/O – fail safe
DP Control System	Common Power supplies and I/O sharing references and sensors
Data Communication Networks	Commonality at each data consumer – Network storm protection

APPENDIX 3. ADHERENCE TO SEVEN PILLARS

A3.1. COMPARATOR TOOL

The comparator tool from MTS TECHOP (D-01 - Rev1 - Jan21) ADDRESSING C³EI² TO ELIMINATE SINGLE POINT FAILURES was used to produce a Heat Map for the Redundancy concept to assess the robustness of the design and its reliance on compensating provisions. Reference can be made to TECHOP (D-11 - Rev1 - Jan21) REDUNDANCY CONCEPT PHILOSOPHY DOCUMENT for further information on how the tool is used.

Appendix 3 - Table 1 Comparator Tool (INPUT)

Seven Pillars – Comparator			**Independent Autonomy Independence Segregation**	**Common (Non-Independent) Closed Busties (Reliance on Protective Functions) Dual Feed (Reliance on Protection and ride-through) Reliance on Standby Start Reliance on Changeover Pipework (Reliance on protection against mechanical damage and performance attributes)** **Intention to Validate by Testing?**		**Remarks Percentage of common (non-independent) 'Yes' and 'No' entries in total DP system is an indicator of: · Reliance on active measure or exemption from consideration · Verification and validation burden Percentage of Common (non-independent) 'No' entries in the total number of Common Systems is an indication of the robustness of the redundancy concept.**
System	**Subsystem**	**Not Applicable**	**Yes**	**Yes**	**No**	
1. Select Not Applicable if necessary (✓) 2. Tick One Box in Each Row 3. Review Heatmap to check completion						
Marine Auxiliary Systems	Fuel MDO/HFO		✓			ME has independent power source
	Seawater Cooling			✓		Only main pipework is common
	Freshwater Cooling		✓			ME has independent power source
	Lubricating Oil			✓		Common system but robust measures in place to prevent contamination etc
	Service Air			✓		Compressed air consumers fail safe
	Starting Air			✓		Compressed air consumers fail safe

Seven Pillars – Comparator			Independent Autonomy Independence Segregation	Common (Non-Independent) Closed Busties (Reliance on Protective Functions) Dual Feed (Reliance on Protection and ride-through) Reliance on Standby Start Reliance on Changeover Pipework (Reliance on protection against mechanical damage and performance attributes)		Remarks Percentage of common (non-independent) 'Yes' and 'No' entries in total DP system is an indicator of: · Reliance on active measure or exemption from consideration · Verification and validation burden
				Intention to Validate by Testing?		
System	Subsystem	Not Applicable	Yes	Yes	No	Percentage of Common (non-independent) 'No' entries in the total number of Common Systems is an indication of the robustness of the redundancy concept.
1. Select Not Applicable if necessary (✓) 2. Tick One Box in Each Row 3. Review Heatmap to check completion						
Marine Auxiliary Systems	Instrument Air			✓		Compressed air consumers fail safe
	Combustion Air		✓			Independent from outside
	Ventilation			✓		Some commonality - Will be verified and validated
	HVAC			✓		Some commonality - Will be verified and validated
Power Generation	Engines		✓			All independent
	Engine Control Systems		✓			All independent
	Alternator		✓			All independent
	Governor		✓			All independent
	AVR		✓			All independent
	Protection Systems		✓			All independent
Power Distribution	Main Power Generation Level			✓		closed busties with comprehensive verification and validation
	Auxiliary Systems Power Distribution Level		✓			independent

Seven Pillars – Comparator			Independent Autonomy Independence Segregation	Common (Non-Independent) Closed Busties (Reliance on Protective Functions) Dual Feed (Reliance on Protection and ride-through) Reliance on Standby Start Reliance on Changeover Pipework (Reliance on protection against mechanical damage and performance attributes) Intention to Validate by Testing?		Remarks Percentage of common (non-independent) 'Yes' and 'No' entries in total DP system is an indicator of: · Reliance on active measure or exemption from consideration · Verification and validation burden Percentage of Common (non-independent) 'No' entries in the total number of Common Systems is an indication of the robustness of the redundancy concept.
System	Subsystem	Not Applicable	Yes	Yes	No	
1. Select Not Applicable if necessary (✓) 2. Tick One Box in Each Row 3. Review Heatmap to check completion						
Power Distribution	Small Power and Lighting Level		✓			independent
	Control Power 110Vdc / 24Vdc		✓			independent
Power Management	Operator Stations		✓			Independent (common networks are considered separately)
	Field Stations		✓			independent (common networks are considered separately)
	Load Sharing		✓			Open busties no load sharing
	VAR Sharing (ac)		✓			
Energy Management	Battery Management Systems		✓			
	Battery / Capacitor Systems		✓			
	Energy		✓			
	Regeneration	✓				
	Dynamic Breaking	✓				

Seven Pillars – Comparator			Independent Autonomy Independence Segregation	Common (Non-Independent) Closed Busties (Reliance on Protective Functions) Dual Feed (Reliance on Protection and ride-through) Reliance on Standby Start Reliance on Changeover Pipework (Reliance on protection against mechanical damage and performance attributes) Intention to Validate by Testing?		Remarks Percentage of common (non-independent) 'Yes' and 'No' entries in total DP system is an indicator of: · Reliance on active measure or exemption from consideration · Verification and validation burden Percentage of Common (non-independent) 'No' entries in the total number of Common Systems is an indication of the robustness of the redundancy concept.
System	**Subsystem**	**Not Applicable**	**Yes**	**Yes**	**No**	
1. Select Not Applicable if necessary (✓) 2. Tick One Box in Each Row 3. Review Heatmap to check completion						
Data Communication Networks	Networks			✓		common - Network storm and through-put will be carried out
	Network Power Supplies		✓			Independent
Thrusters	Thrust Magnitude Control		✓			Independent
	Thrust Direction Control		✓			Independent
	Thruster Control Mode Selection			✓		Still a common point but will be tested.
	E Stop		✓			Independent
DP Control System	Controllers			✓		Duty Standby C/O will be verified
	Operator Stations			✓		Operator stations are common to both controllers
	Power Supplies			✓		Power supplies are shared between A & B in standard delivery but will be tested
	UPS		✓			Independent UPS

Seven Pillars – Comparator			Independent Autonomy Independence Segregation	Common (Non-Independent) Closed Busties (Reliance on Protective Functions) Dual Feed (Reliance on Protection and ride-through) Reliance on Standby Start Reliance on Changeover Pipework (Reliance on protection against mechanical damage and performance attributes) Intention to Validate by Testing?		Remarks Percentage of common (non-independent) 'Yes' and 'No' entries in total DP system is an indicator of: · Reliance on active measure or exemption from consideration · Verification and validation burden Percentage of Common (non-independent) 'No' entries in the total number of Common Systems is an indication of the robustness of the redundancy concept.
System	Subsystem	Not Applicable	Yes	Yes	No	
1. Select Not Applicable if necessary (✓) 2. Tick One Box in Each Row 3. Review Heatmap to check completion						
DP Control System	PRS			✓		Standard DP control system - will be tested
	Sensors			✓		Standard DP control system will be tested
Safety Systems	ESD	✓				
	F&G	✓				
	Fifi	✓				
	E Stop			✓		Common software but separate I/O - will be tested

A3.2. DP SYSTEM HEAT MAP

A3.2.1. Appendix 3 - Table 2 is the heat map produced by the comparator tool applied to the redundancy concept? Commentary on the results of the tool is provided in Section A3.3.

Appendix 3 - Table 2 Heat Map

DP System Heat Map

Total Score 56

Marine Auxiliary Systems	Power Generation	Power Distribution	Power Management	Energy Management	Data Comm Networks	Thrusters	DP Control System	Safety Systems
17	**6**	**5**	**4**	**3**	**3**	**5**	**11**	**2**
Summary Score	**Summary Score**	**Summary Score**	**Summary Score**	**Summary Score**	**Summary Score**	**Summary Score**	**Summary Score**	**Summary Score**
Fuel MDO/HFO	Engines	Main Power Generation Level	Operator Stations	Battery Management Systems	Networks	Thrust Magnitude Control	Controllers	ESD
Seawater Cooling	Engine Control Systems	Auxiliary Systems Power Distribution Level	Field Stations	Battery / Capacitor Systems	Network Power Supplies	Thrust Direction Control	Operator Stations	F&G
Freshwater Cooling	Alternator	Small Power and Lighting Level	Load Sharing	Energy		Thruster Control Mode Selection	Power Supplies	Fifi
Lubricating Oil	Governor	Control Power (110Vdc / 24Vdc)	VAR Sharing (ac)	Regeneration		E Stop	UPS	E Stop
Service Air	AVR			Dynamic Breaking			PRS	
Starting Air	Protection Systems						Sensors	
Instrument Air								
Combustion Air								
Ventilation								
HVAC								

Independence in Design	**60%**
Commonalities (Non-Independent) in design with intention to verify and validate	**40%**
Commonalities (Non-Independent) in design without intention to verify and validate	**0%**
Not Applicable	**5**
Total Completion	**100%**
Reliance on active mitigation, exemption from consideration and verification and validation burden	**41%**
Robustness of the redundancy concept (Analysis of common (non-independent) systems)	**100%**

A3.3. COMMENTRY HEAT MAP RESULTS

A3.3.1. Total Score: 56.

- 44 is a perfect score in a redundancy concept where all listed systems are applicable, and all systems are entirely independent.
- 132 indicates that every system has commonality and there is no intention to verify and validate the compensating provisions.
- This concept score 56 indicating a low level of commonality.

A3.3.2. Independence in design (60%): A figure of 60% indicates a moderate degree of commonality associated with lower risk commonality in system such as the main seawater because it is likely to be uneconomic and unnecessary to remove it.

A3.3.3. Commonalities in design with intention to verify and validate (40%): Indicated there are few commonalties of any kind in the design and all of them will be validated.

A3.3.4. Commonalities in design without intention to verify and validate (0%): The commitment to robust verification and validation.

A3.3.5. Not applicable (5): There are some additional ‘applicable; systems associated with the stored energy for the main engine, but they are all independent.

A3.3.6. Total completion (100%): The analyses was completed as indicted by the green banner in the tool output.

A3.3.7. **Reliance** on active mitigation, exemption, V&V burden (41%): This figure is commensurate with DP systems operating with closed busties are reliant on a wide range of protective functions.

A3.3.8. **Robustness** of the redundancy concept (100%): This high figure is entirely due to the commitment to comprehensibly verify and validate all compensating provisions.

APPENDIX 4. ALTERNATIVE MAIN SWITCHBOARD ARRANGEMENTS

A4.1. ADDITIONAL MAIN BUS CONFIGURATIONS

A4.1.1. The modular and autonomous nature of the AKA thruster and generator design means it can readily be adapted to different switchboard configurations.

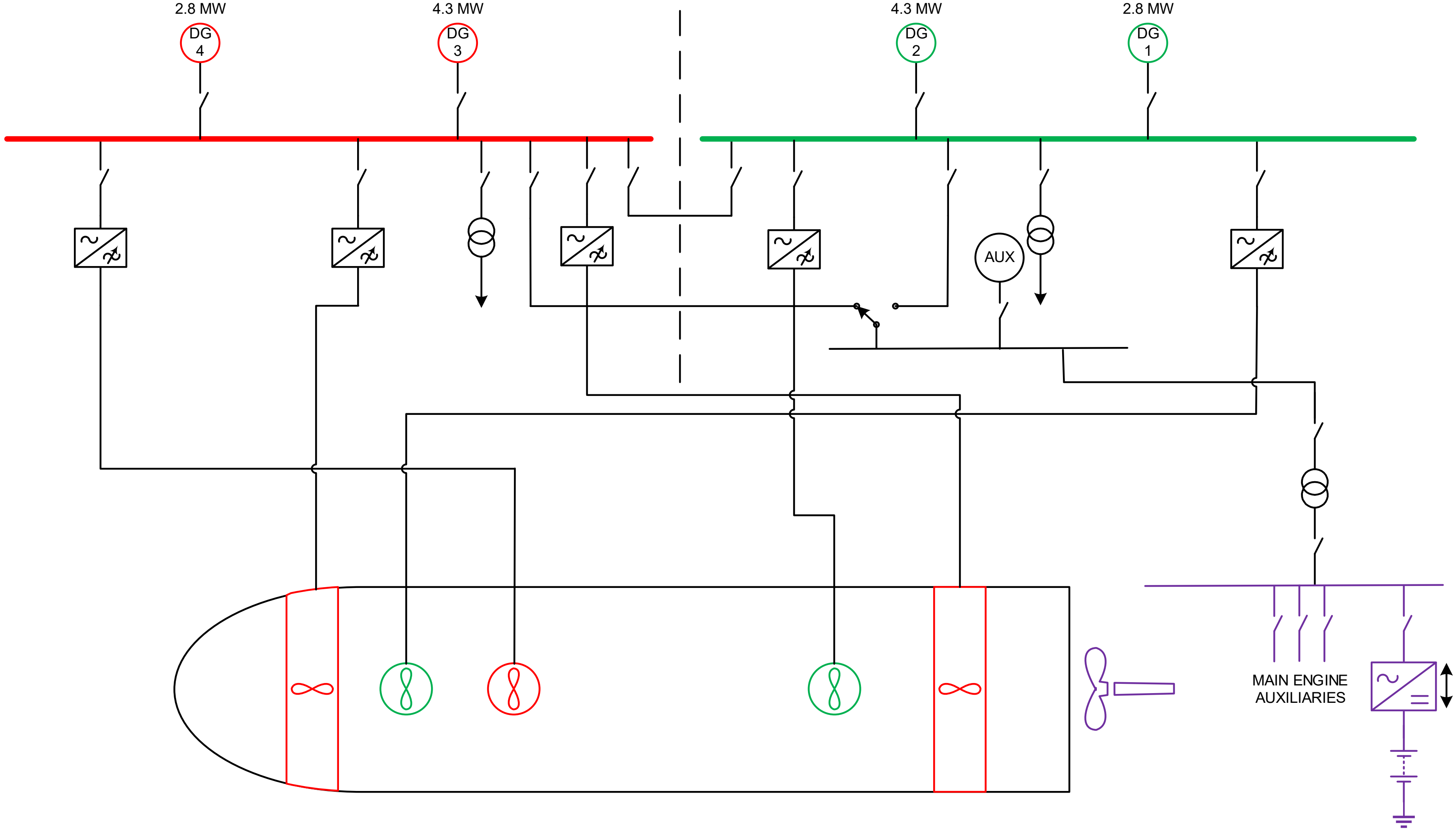
A4.1.2. A four-way split was used as the basis of the redundancy concept described in this RCPD. Alternative configurations for two-way split and three-way split are provided in the sections that follow.

A4.1.3. Although the post failure capability for Dynpos (AUTR) would change according to the bus bar configuration, the LIFE concept post failure capability would be determined by the capacity of the surviving generators and thrusters. Although the same thruster and main engine configuration has been retained. It is envisaged that there could be different numbers and ratings of generators.

A4.1.4. Changing the number of switchboards has little impact on the score obtained using the seven pillars comparator tool provided the same attention is paid to common points between redundant equipment groups.

A4.2. TWO-WAY SPLIT

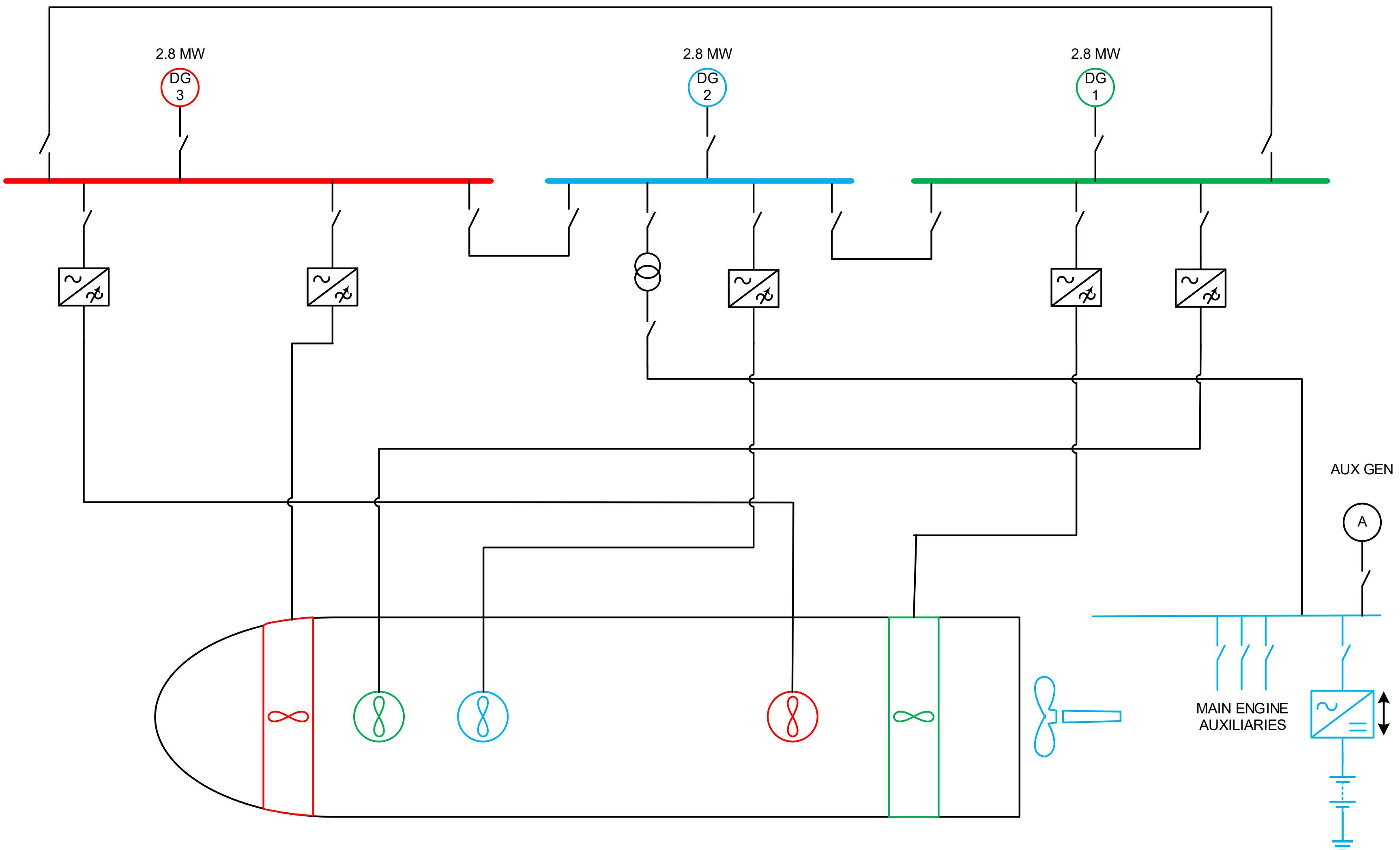
A4.2.1. Appendix 4 - Figure 1 shows an arrangement based on two main switchboards. All other aspects of the design remain the same including the thruster and main engine configuration. Although this appears to be based on three independent groups, everything except the main switchboards would be designed for five independent groups.



Appendix 4 - Figure 1 **Two-way Split**

A4.3. THREE-WAY SPLIT

A4.3.1. Appendix 4 - Figure 2 shows an arrangement based on three main switchboards. The same thruster and main engine configuration have been retained but the number of generators has been reduced from four (in two sizes) to three of the larger units. Alternatively, six smaller units may offer advantages. Although this appears to be based on four independent groups (three switchboards plus main engine, CPP & rudder), everything except the main switchboard bus sections would be designed for five independent groups.



Appendix 4 - Figure 2 Three-way Split