

GENERAL SPECIFICATION

Field Operations

GS EP EXP 405

Standard Reliability Data

03	12/2017	Update with new reliability data set
02	05/2015	Organisation change – January 2015
01	01/2012	Update following the EP reorganization, march 2011
00	01/2011	First Issue
Rev.	Date	Purpose of the revision

Owning entity: DSO/IP/EXP	Managing entity: DSO/IP/EXP
Other Approving entity(ies):	

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1. Scope

This General Specification proposes a set of reliability data which have been checked and validated by reliability experts from Maintenance & Inspection Methods.

Limits: The present General Specification does not include reliability data for:

- LNG equipment;
- Electronic components (e.g. microprocessors);
- Control systems (e.g. input/output interface modules, F&G controllers);
- Mining, arctic and other particular environment;
- Human errors.

2. Reference documents

The reference documents listed below form an integral part of this General Specification.

External Documents

Unless otherwise stipulated, the applicable version of these documents, including relevant appendices and addendums, is the latest revision published at the effective date of this document.

Reference	Title
EIReDA	The European Industry Reliability Data bank
ISO 14224	Petroleum, petrochemical and natural gas industries – Collection and exchange of reliability and maintenance data for equipment
OREDA Handbook	Offshore Reliability Data – 6 th Edition – 2015
SERH	Safety Equipment Reliability Handbook, 4 th Edition, 2015, exida

Total General Specifications

Unless otherwise stipulated, the applicable version of these documents, including relevant appendices and addendums, is the latest revision published.

Reference	Title
GS EP EXP 403	Production Availability Studies of oil and gas facilities
GS EP SAF 260	Design of High Integrity Protection Systems (HIPS)

3. Terminology & Abbreviation

3.1 Terms and definitions

For the purpose of this document, the following terms and definitions apply.

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Accumulated Active Repair Time: Accumulated duration of the individual maintenance times used by all maintenance personnel for corrective maintenance action, excluding logistic delays.

Active Repair Time: Effective time to achieve repair of an item.

Availability: Ability to be in a state to perform as required.

Boundary: Interface between an item and its surroundings.

Calendar Time: Interval of time (surveillance time) between the start date and end date of Reliability/Maintenance data collection.

Corrective Maintenance: Maintenance carried out after fault detection to effect restoration.

Critical Failure: Failure of an equipment unit that causes an immediate cessation of the ability to perform a required function.

Degraded Failure: Failure that does not cease the fundamental function(s), but compromises one or several functions.

Demand: Activation of the function (includes functional, operational and test activation).

Equipment Class: Class of similar type of equipment units (e.g. all compressors).

Equipment Data: Technical, operational and environmental parameters characterizing the design and use of an equipment unit.

Equipment Unit: Specific equipment unit within an equipment class as defined by its boundary (e.g. one pump).

Failure Data: Data characterizing the occurrence of a failure event.

Failure mode: manner in which failure occurs.

Fail while running: Failures occurring while the equipment is running.

Fail to start: Failure discovered during an on-demand attempt to activate an equipment unit (e.g. safety valve fail to close on ESD signal, fail to start a gas turbine on demand)

Incipient Failure: Imperfection in the state or condition of an item so that a degraded or critical failure might (or might not) eventually be the expected result if corrective actions are not taken.

Installation: Number of areas in which the item is located.

Lower/Upper: Confidence intervals are used to indicate the reliability of an estimate. Concerning failure and repair rates, the χ^2 distribution will be used to estimate the bounds (Lower and Upper) of the 90% confidence interval.

Operating Time: Time interval during which an item is in operating state.

Population: The total number of items of one particular type in service during the period of the event data surveillance.

Reliability: Ability of an item to perform a required function under given conditions for a given time interval.

Severity Classification: Describes effect on operational status and the severity of loss of output from the system. The severity classification is connected to the ability of the item in question to perform its function.

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Subunit: Assembly of items that provides a specific function that is required for the equipment unit within the main boundary to achieve its intended performance.

Taxonomy: Systematic classification of items into generic groups based on factors possibly common to several of the items.

Unknown Failure: Too little information to define a failure mode.

3.2 Abbreviation and symbols

λ	Failure Rate
γ	Probability of Failure due to Demands
μ	Active Repair Rate
AC	Alternating Current
AMV	Annulus Master Valve
AWV	Annulus Wing Valve
BDV	Blow Down Valve
DC	Direct Current
ESD	Emergency Shut Down
ESDV	Emergency Shut Down Valve
ESP	Electrical Submersible Pump
ESPCP	Electrical Submersible Progressive Cavity Pump
FCV	Flow Control Valve
F&G	Fire & Gas
HC	Hydro-Carbons
IMV	Injection Master Valve
IWV	Injection Wing Valve
LCV	Level Control Valve
LNG	Liquefied Natural Gas
MTTF	Mean Time To Failure
MTTR	Mean active Time To Repair
NA	Not Applicable
PCP	Progressive Cavity Pump
PCV	Pressure Control Valve
PD pump	Progressive Displacement pump
PMV	Production Master Valve
PWV	Production Wing Valve
PSV	Pressure Safety Valve
SDV	Shut Down Valve

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SEM	Subsea Electronic Module
SIL	Safety Integrity Level
SRU	Sulphate Removal Unit
TR-SCSSV	Tubing Retrievable Surface Controlled Sub Surface Valve
TSV	Temperature Safety Valve
TUTU	Topside Umbilical Termination Unit
UPS	Uninterruptible Power Supply
WH	Well Head
WHRU	Waste Heat Recovery Unit
WR-SCSSV	Wireline Retrievable Surface Controlled Sub Surface Valve
XT	Xmas Tree

4. Domain of use of the reliability data

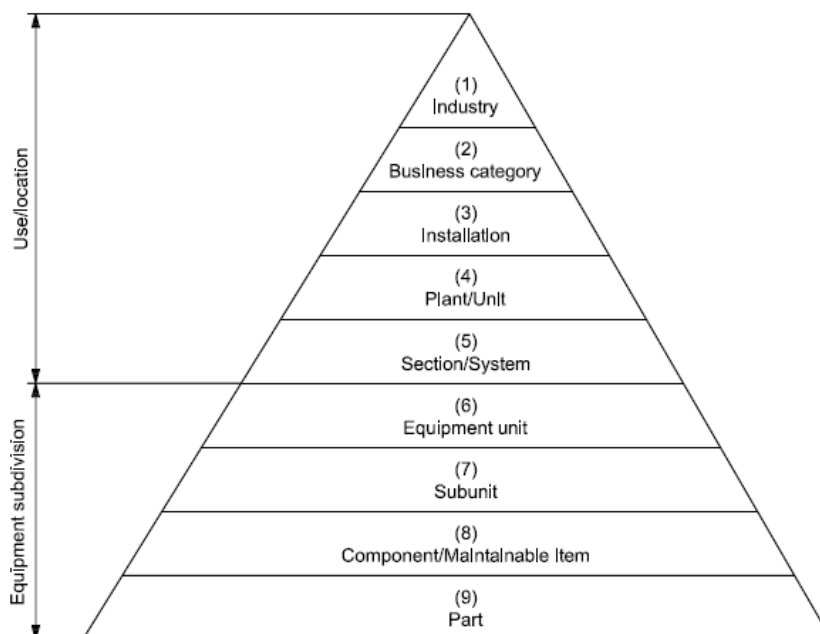
{Rule 1:

The present reliability data shall be used for all production availability studies (**GS EP EXP 403**), SIL assessment or SIL achievement studies (**GS EP SAF 260**) and all other studies involving the use of reliability data.}

5. Structure of the reliability data set

5.1 Taxonomy

The structure of data follows the taxonomy used in the [ISO 14224](#), illustrated in the figure 1, and considers an approach by equipment.


Figure 1: Taxonomy

The equipment subdivision enables the following hierarchy to be defined:

- Topside data:
 - Equipment Unit;
 - Subunit;
 - Maintainable Item.
- Subsea data:
 - Equipment Unit;
 - Subunit;
 - Component.

5.2 Data quality

In statistics, good estimations require to use large and heterogeneous samples. Three levels of confidence were defined: good, satisfactory and poor. The criteria detailed in Table 1 are used to define the sample quality:

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Table 1: Level of confidence criteria

Good	N° of Installations ≥ 5 AND Population ≥ 30 AND Total Operational Time ≥ 80 years (~700,000 hrs)
Poor	N° of Installations < 3 OR [Population < 10 AND Total Operational Time < 20 years (~175,000 hrs)]
Satisfactory	Others

A quotation of the quality of each sample has been achieved, according to the above-mentioned quality rules and the Data Source used, in order to have information about the level of confidence which can be placed on estimates.

5.3 Assumptions

5.3.1 Failure and repair rate distribution

It is assumed that each equipment is in its useful life phase and therefore that the failure rate function is presumed to be constant.

In the same way, the repair rate function is presumed to be constant. This parameter has been preferred to the MTTR in order to avoid that the repair time can be considered as a deterministic event.

5.3.2 Failure rate estimation with zero failures

Some equipment experience zero failures despite a long operational time.

One of the well-known method to estimate the failure rate is to calculate the upper limit of the one-sided confidence interval at the 50% confidence level. This value is such that the real value has the same probability (0.5) to be lower or higher.

$$\lambda = \frac{\chi_{0,5}^2(2)}{2T} \cong \frac{0,7}{T}$$

Where T is the operational time.

6. Use of other reliability data sources

{Rule 2:

The use of other reliability databases shall be explained, justified and referenced for equipment which are included in the present general specifications.}

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{Rule 3:

The correct conduct of data research shall follow the hierarchy presented in the Figure 2.}

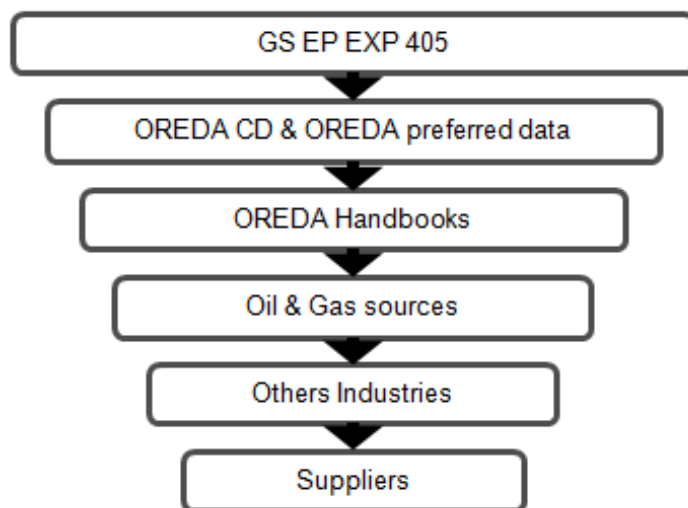


Figure 2: Data Sources hierarchy

7. Reliability data

Equipment's reliability data are presented in the following appendices:

- Appendix 1: Well equipment
- Appendix 2: Rotating equipment;
- Appendix 3: Electrical equipment;
- Appendix 4: Mechanical equipment;
- Appendix 5: Safety & Control;
- Appendix 6: Subsea equipment;
- Appendix 7: Conversion Table.



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Bibliography

Reference

OREDA Software

Title of the publication

Database Release 11.2 July 2016

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Appendix 1

Appendix 1 Well equipment

1.1 Valves

TR-SCSSV/Oil well

Data Source		Sample Quality		Aggregated Time-in-service (Years)						
In-house data		NA		Operational Time						
Completions	Fields	Failure Data					Repair Data			
		Nb. of Failures	MTTF (in years)	Failure Rate (per 10 ⁶ hours)			MTTR (in hours)	Active repair rate (per 10 ² hours)		
Severity Class	Failure Mode			Lower	λ	Upper		Lower	μ	Upper
Critical	for safety		27.2		4.19					
Critical	for production		150.4		0.76					

TR-SCSSV/Gas well

Data Source		Sample Quality		Aggregated Time-in-service (Years)						
In-house data		NA		Operational Time						
Completions	Fields	Failure Data					Repair Data			
		Nb. of Failures	MTTF (in years)	Failure Rate (per 10 ⁶ hours)			MTTR (in hours)	Active repair rate (per 10 ² hours)		
Severity Class	Failure Mode			Lower	λ	Upper		Lower	μ	Upper
Critical	for safety		49.1		2.32					
Critical	for production		129.1		0.88					

TR-SCSSV/Water well

Data Source		Sample Quality		Aggregated Time-in-service (Years)						
In-house data		NA		Operational Time						
Completions	Fields	Failure Data					Repair Data			
		Nb. of Failures	MTTF (in years)	Failure Rate (per 10 ⁶ hours)			MTTR (in hours)	Active repair rate (per 10 ² hours)		
Severity Class	Failure Mode			Lower	λ	Upper		Lower	μ	Upper
Critical	for safety		68.5		1.67					
Critical	for production		362.3		0.32					

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Appendix 1
WR-SCSSV/Oil well

Data Source		Sample Quality		Aggregated Time-in-service (Years)						
In-house data		NA		Operational Time						
Completions	Fields	Failure Data					Repair Data			
		Nb. of Failures	MTTF (in years)	Failure Rate (per 10 ⁶ hours)			MTTR (in hours)	Active repair rate (per 10 ² hours)		
Severity Class	Failure Mode			Lower	λ	Upper		Lower	μ	Upper
Critical	for safety		8.5		13.40					
Critical	for production		17.2		6.64					

WR-SCSSV/Gas well

Data Source		Sample Quality		Aggregated Time-in-service (Years)						
In-house data		NA		Operational Time						
Completions	Fields	Failure Data					Repair Data			
		Nb. of Failures	MTTF (in years)	Failure Rate (per 10 ⁶ hours)			MTTR (in hours)	Active repair rate (per 10 ² hours)		
Severity Class	Failure Mode			Lower	λ	Upper		Lower	μ	Upper
Critical	for safety		34.6		3.30					
Critical	for production		34.0		3.36					

WR-SCSSV/Water well

Data Source		Sample Quality		Aggregated Time-in-service (Years)						
In-house data		NA		Operational Time						
Completions	Fields	Failure Data					Repair Data			
		Nb. of Failures	MTTF (in years)	Failure Rate (per 10 ⁶ hours)			MTTR (in hours)	Active repair rate (per 10 ² hours)		
Severity Class	Failure Mode			Lower	λ	Upper		Lower	μ	Upper
Critical	for safety		36.3		3.15					
Critical	for production		84.6		1.35					

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Appendix 1
TR-SCASSV/Gas injection.

Data Source		Sample Quality		Aggregated Time-in-service (Years)						
In-house data		NA		Operational Time						
Completions	Fields	Failure Data					Repair Data			
		Nb. of Failures	MTTF (in years)	Failure Rate (per 10 ⁶ hours)			MTTR (in hours)	Active repair rate (per 10 ² hours)		
Severity Class	Failure Mode			Lower	λ	Upper		Lower	μ	Upper
Critical	for safety		38.4		2.97					
Critical	for production		106.6		1.07					

1.2. Pumps
Electric submersible pumps (ESP)

Data Source		Sample Quality		Aggregated Time-in-service (Years)						
In-house data		NA		Operational Time						
Installation	Population	Failure Data					Repair Data			
		Nb. of Failures	MTTF (in years)	Failure Rate (per 10 ⁶ hours)			MTTR (in hours)	Active repair rate (per 10 ² hours)		
Severity Class	Failure Mode			Lower	λ	Upper		Lower	μ	Upper
Critical	All		2.5		45.66					

Electric submersible progressive cavity pumps (ESPCP)

Data Source		Sample Quality		Aggregated Time-in-service (Years)						
In-house data		NA		Operational Time						
Installation	Population	Failure Data					Repair Data			
		Nb. of Failures	MTTF (in years)	Failure Rate (per 10 ⁶ hours)			MTTR (in hours)	Active repair rate (per 10 ² hours)		
Severity Class	Failure Mode			Lower	λ	Upper		Lower	μ	Upper
Critical	All		1.5		76.10					

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Appendix 1

Progressive cavity pumps (PCP)

Data Source		Sample Quality		Aggregated Time-in-service (Years)						
In-house data		NA		Operational Time						
Installation	Population	Failure Data					Repair Data			
		Nb. of Failures	MTTF (in years)	Failure Rate (per 10 ⁶ hours)			MTTR (in hours)	Active repair rate (per 10 ² hours)		
Severity Class	Failure Mode			Lower	λ	Upper		Lower	μ	Upper
Critical	All		1.0		114.16					

Appendix 2 Rotating equipment

2.1. Compressors

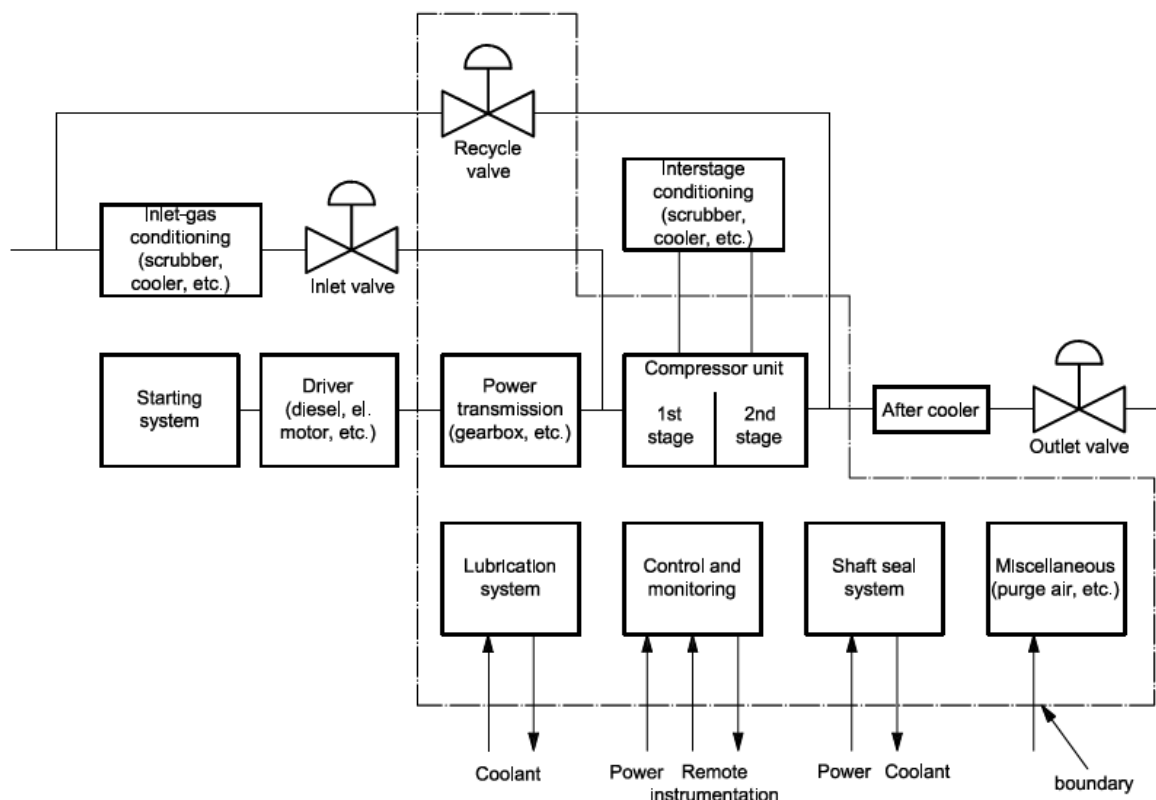


Figure 3: Boundary Definition – Compressors

Air Compressors/all

Data Source		Sample Quality		Aggregated Time-in-service (years)			Failure due to Demands			
OREDA		Good					Operational Time		Probability (γ)	
				121						
				Installations	Population	Failure Data				
29	72	Nb. of Failures	MTTF (in years)	Failure Rate (per 10 ⁶ hours)			MTTR (in hours)	Active repair rate (per 10 ² hours)		
Severity Class	Failure Mode			Lower	λ	Upper		Lower	μ	Upper
Critical	Fail while running	52	2.3	38.41	49.04	61.78	21.0	3.73	4.76	6.00
	Fail to start	13	9.3	7.25	12.26	19.49	22.0	2.69	4.55	7.23
Degraded	All	134	0.9	108.52	125.89	145.35	20.8	4.15	4.81	5.56

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Appendix 2
Air Compressors/Centrifugal

Data Source		Sample Quality		Aggregated Time-in-service (years)			Failure due to Demands			
OREDA		Satisfactory					Operational Time		Probability (γ)	
				28						
				Installations	Population	Failure Data				
6	16	Nb. of Failures	MTTF (in years)	Failure Rate (per 10 ⁶ hours)			MTTR (in hours)	Active repair rate (per 10 ² hours)		
Severity Class	Failure Mode			Lower	λ	Upper		Lower	μ	Upper
Critical	Fail while running	14	2.0	34.94	57.79	90.34	12.0	5.04	8.33	13.03
	Fail to start	4	6.9	5.64	16.51	37.78	4.0	8.54	25.00	57.21
Degraded	All	37	0.7	113.90	152.72	200.91	9.6	8.14	10.43	13.19

Air Compressors/Reciprocating

Data Source		Sample Quality		Aggregated Time-in-service (years)			Failure due to Demands			
OREDA		Satisfactory		Operational Time			Probability (γ)		MTTR (in hours)	
				11						
Installations	Population	Failure Data					Repair Data			
7	14	Nb. of Failures	MTTF (in years)	Failure Rate (per 10 ⁶ hours)			MTTR (in hours)	Active repair rate (per 10 ² hours)		
Severity Class	Failure Mode			Lower	λ	Upper		Lower	μ	Upper
Critical	Fail while running	12	1.0	69.27	120.05	194.50	23.0	2.51	4.35	7.04
	Fail to start	3	3.8	8.18	30.01	77.57	76.0	0.36	1.32	3.40
Degraded	All	39	0.3	289.05	385.15	503.94	26.5	2.83	3.77	4.94

Air Compressors/Screw

Data Source		Sample Quality		Aggregated Time-in-service (years)			Failure due to Demands			
OREDA		Good					Operational Time		Probability (γ)	
				82						
				Installations	Population	Failure Data				
17	42	Nb. of Failures	MTTF (in years)	Failure Rate (per 10 ⁶ hours)			MTTR (in hours)	Active repair rate (per 10 ² hours)		
Severity Class	Failure Mode			Lower	λ	Upper		Lower	μ	Upper
Critical	Fail while running	26	3.2	25.37	36.20	50.23	25.0	2.80	4.00	5.55
	Fail to start	6	13.7	3.64	8.35	16.49	7.0	6.22	14.29	28.20
Degraded	All	45	1.8	47.52	61.96	79.56	28.9	2.66	3.46	4.45

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Appendix 2
Gas Compressors/All

Data Source		Sample Quality		Aggregated Time-in-service (years)			Failure due to Demands			
OREDA		Good					Operational Time		Probability (γ)	
				263		6.50E-04		25.1		
Installations	Population	Failure Data					Repair Data			
18	66	Nb. of Failures	MTTF (in years)	Failure Rate (per 10 ⁶ hours)			MTTR (in hours)	Active repair rate (per 10 ² hours)		
Severity Class	Failure Mode			Lower	λ	Upper		Lower	μ	Upper
Critical	Fail while running	424	0.6	169.46	184.18	199.34	12.0	7.67	8.33	9.02
	Fail to start	16	16.4	4.36	6.95	10.56	46.0	1.36	2.17	3.30
Degraded	All	922	0.3	378.80	400.50	422.64	12.2	7.74	8.18	8.63

Gas Compressors/Centrifugal

Data Source		Sample Quality		Aggregated Time-in-service (years)			Failure due to Demands			
OREDA		Good					Operational Time		Probability (γ)	
				223		5.60E-03		27.0		
Installations	Population	Failure Data					Repair Data			
13	47	Nb. of Failures	MTTF (in years)	Failure Rate (per 10 ⁶ hours)			MTTR (in hours)	Active repair rate (per 10 ² hours)		
Severity Class	Failure Mode			Lower	λ	Upper		Lower	μ	Upper
Critical	Fail while running	82	2.7	34.69	42.02	50.49	28.0	2.95	3.57	4.29
	Fail to start	14	15.9	4.34	7.17	11.21	49.0	1.23	2.04	3.19
Degraded	All	525	0.4	249.44	268.74	288.58	19.3	4.82	5.19	5.57

Gas Compressors/Reciprocating

Data Source		Sample Quality		Aggregated Time-in-service (years)			Failure due to Demands			
OREDA		Poor					Probability (γ)		MTTR (in hours)	
				Operational Time						
			11			1.90E-04		34.5		
Installations	Population	Failure Data					Repair Data			
4	5	Nb. of Failures	MTTF (in years)	Failure Rate (per 10 ⁶ hours)			MTTR (in hours)	Active repair rate (per 10 ² hours)		
Severity Class	Failure Mode			Lower	λ	Upper		Lower	μ	Upper
Critical	Fail while running	11	1.0	66.16	117.98	195.28	33.0	1.70	3.03	5.02
	Fail to start	1	10.6	0.55	10.73	50.88	44.0	0.12	2.27	10.78
Degraded	All	34	0.3	268.23	364.65	485.47	15.1	4.87	6.61	8.81

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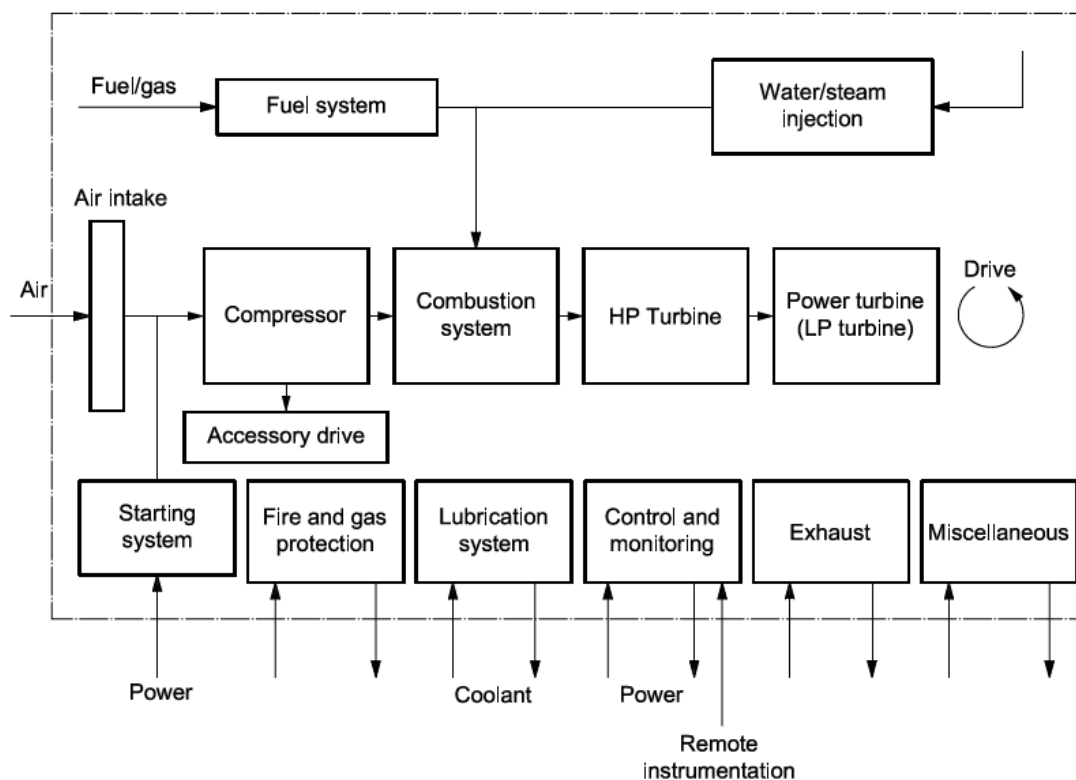
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Appendix 2
Gas Compressors/Screw.

Data Source		Sample Quality		Aggregated Time-in-service (years)			Failure due to Demands			
OREDA		Poor					Probability (γ)		MTTR (in hours)	
				Operational Time						
7			1.80E-04		5.9					
Installations	Population	Failure Data					Repair Data			
2	3	Nb. of Failures	MTTF (in years)	Failure Rate (per 10 ⁶ hours)			MTTR (in hours)	Active repair rate (per 10 ² hours)		
Severity Class	Failure Mode			Lower	λ	Upper		Lower	μ	Upper
Critical	Fail while running	44	0.2	539.72	704.96	906.39	11.0	6.96	9.09	11.69
	Fail to start	6	1.2	41.87	96.13	189.74	5.0	8.71	20.00	39.47
Degraded	All	107	0.1	1443.76	1706.32	2004.38	6.9	12.29	14.52	17.06

2.2. Gas turbines

Figure 4: Boundary Definition - Gas turbines

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Appendix 2
Gas turbines/All

Data Source		Sample Quality		Aggregated Time-in-service (years)			Failure due to Demands			
OREDA		Good					Operational Time		Probability (γ)	
				181						
						1.60E-02		25.6		
Installations	Population	Failure Data					Repair Data			
18	51	Nb. of Failures	MTTF (in years)	Failure Rate (per 10 ⁶ hours)			MTTR (in hours)	Active repair rate (per 10 ² hours)		
Severity Class	Failure Mode			Lower	λ	Upper		Lower	μ	Upper
Critical	Fail while running	164	1.1	90.72	103.67	118.01	25.0	3.52	4.00	4.53
	Fail to start	44	4.1	21.29	27.81	35.76	12.0	6.42	8.33	10.66
Degraded	All	545	0.3	319.93	344.19	369.11	11.3	8.23	8.83	9.44

Gas turbines/Aero derivative

Data Source		Sample Quality		Aggregated Time-in-service (years)			Failure due to Demands			
OREDA		Good					Operational Time		Probability (γ)	
				161		1.60E-02		22.4		
Installations	Population	Failure Data					Repair Data			
14	43	Nb. of Failures	MTTF (in years)	Failure Rate (per 10 ⁶ hours)			MTTR (in hours)	Active repair rate (per 10 ² hours)		
Severity Class	Failure Mode			Lower	λ	Upper		Lower	μ	Upper
Critical	Fail while running	111	1.5	66.69	78.54	91.95	20.0	4.28	5.00	5.81
	Fail to start	28	5.8	14.08	19.81	27.16	13.0	5.43	7.69	10.61
Degraded	All	298	0.5	191.18	210.86	232.08	10.9	8.55	9.20	9.86

Gas turbines/Industrial

Data Source		Sample Quality		Aggregated Time-in-service (years)			Failure due to Demands				
OREDA		Good					Operational Time		Probability (γ)		MTTR (in hours)
				240		1.80E-02		30.5			
Installations	Population	Failure Data						Repair Data			
16	64	Nb. of Failures	MTTF (in years)	Failure Rate (per 10 ⁶ hours)			MTTR (in hours)	Active repair rate (per 10 ² hours)			
Severity Class	Failure Mode			Lower	λ	Upper		Lower	μ	Upper	
Critical	Fail while running	245	1.0	104.51	116.47	129.48	26.0	3.45	3.85	4.27	
	Fail to start	90	2.7	35.65	42.79	50.98	31.0	2.70	3.23	3.83	
Degraded	All	536	0.4	236.71	254.81	273.41	18.7	4.98	5.35	5.72	

2.3. Pumps

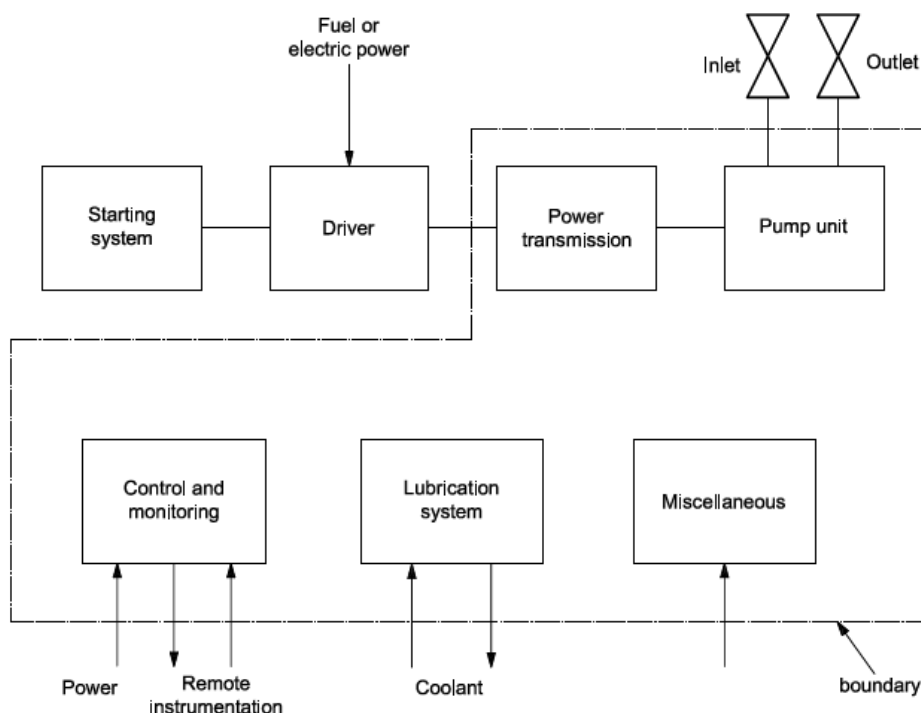


Figure 5: Boundary Definition - Pumps

(*) Zero failures estimator. Refer to section 5.4.2

Pumps/All

Data Source		Sample Quality		Aggregated Time-in-service (years)			Failure due to Demands			
OREDA		Good					Probability (γ)		MTTR (in hours)	
				Operational Time						
620			1.80E-03		56.1					
Installations	Population	Failure Data					Repair Data			
37	284	Nb. of Failures	MTTF (in years)	Failure Rate (per 10 ⁶ hours)			MTTR (in hours)	Active repair rate (per 10 ² hours)		
Severity Class	Failure Mode			Lower	λ	Upper		Lower	μ	Upper
Critical	Fail while running	306	2.0	51.18	56.38	61.97	33.0	2.75	3.03	3.33
	Fail to start	17	36.4	2.00	3.13	4.70	78.0	0.82	1.28	1.92
Degraded	All	452	1.4	76.74	83.18	89.81	23.5	3.92	4.25	4.59

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Appendix 2
Pumps/Centrifugal/All.

Data Source		Sample Quality		Aggregated Time-in-service (years)			Failure due to Demands			
OREDA		Good		Operational Time			Probability (γ)	MTTR (in hours)		
				552						
				Installations	Population	Failure Data				
35	229	Nb. of Failures	MTTF (in years)	Failure Rate (per 10 ⁶ hours)			MTTR (in hours)	Active repair rate (per 10 ² hours)		
Severity Class	Failure Mode			Lower	λ	Upper		Lower	μ	Upper
Critical	Fail while running	288	1.9	53.91	59.56	65.66	33.0	2.74	3.03	3.34
	Fail to start	16	34.5	2.08	3.31	5.03	82.0	0.76	1.22	1.85
Degraded	All	428	1.3	81.37	88.41	95.66	23.7	3.88	4.22	4.56

Pumps/Centrifugal/Chemical injection

Data Source		Sample Quality		Aggregated Time-in-service (years)			Failure due to Demands			
OREDA		Satisfactory					Probability (γ)		MTTR (in hours)	
				Operational Time						
19			1.80E-03		59.0					
Installations	Population	Failure Data					Repair Data			
3	16	Nb. of Failures (*)	MTTF (in years)	Failure Rate (per 10 ⁶ hours)			MTTR (in hours)	Active repair rate (per 10 ² hours)		
Severity Class	Failure Mode			Lower	λ	Upper		Lower	μ	Upper
Critical	Fail while running	0.7	27.1	0.01	4.21	23.47				
	Fail to start	0.7	27.1	0.01	4.21	23.47				
Degraded	All	3	7.6	3.44	15.02	42.26	15.4	1.49	6.49	18.27

Pumps/Centrifugal/Fire fighting

Data Source		Sample Quality		Aggregated Time-in-service (years)			Failure due to Demands			
OREDA		Satisfactory					Probability (γ)		MTTR (in hours)	
				Operational Time						
			27			1.80E-03		59.0		
Installations	Population	Failure Data					Repair Data			
9	57	Nb. of Failures	MTTF (in years)	Failure Rate (per 10 ⁶ hours)			MTTR (in hours)	Active repair rate (per 10 ² hours)		
Severity Class	Failure Mode			Lower	λ	Upper		Lower	μ	Upper
Critical	Fail while running	10	2.7	22.57	41.60	70.57	34.0	1.60	2.94	4.99
	Fail to start	3	9.1	3.40	12.48	32.26	20.0	1.36	5.00	12.92
Degraded	All	27	1.0	79.29	112.33	154.90	17.1	4.13	5.84	8.06

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Appendix 2
Pumps/Centrifugal/Hydrocarbon handling

Data Source		Sample Quality		Aggregated Time-in-service (years)			Failure due to Demands			
OREDA		Good		Operational Time			Probability (γ)	MTTR (in hours)		
				193						
				Installations	Population	Failure Data				
10	53	Nb. of Failures	MTTF (in years)	Failure Rate (per 10 ⁶ hours)			MTTR (in hours)	Active repair rate (per 10 ² hours)		
Severity Class	Failure Mode			Lower	λ	Upper		Lower	μ	Upper
Critical	Fail while running	173	1.1	89.75	102.18	115.92	57.0	1.54	1.75	1.99
	Fail to start	1	193.3	0.03	0.59	2.80	10.0	0.51	10.00	47.44
Degraded	All	137	1.4	69.89	80.92	93.25	20.1	4.30	4.97	5.73

Pumps/Centrifugal/Water injection

Data Source		Sample Quality		Aggregated Time-in-service (years)			Failure due to Demands			
OREDA		Good					Probability (γ)		MTTR (in hours)	
				Operational Time						
195			3.00E-03		87.4					
Installations	Population	Failure Data					Repair Data			
12	58	Nb. of Failures	MTTF (in years)	Failure Rate (per 10 ⁶ hours)			MTTR (in hours)	Active repair rate (per 10 ² hours)		
Severity Class	Failure Mode			Lower	λ	Upper		Lower	μ	Upper
Critical	Fail while running	79	2.5	37.95	46.15	55.65	57.0	1.45	1.75	2.11
	Fail to start	11	17.8	3.60	6.43	10.64	110.0	0.51	0.91	1.50
Degraded	All	231	0.8	120.40	134.65	150.18	29.2	3.07	3.43	3.83

Pumps/Reciprocating/All

Data Source		Sample Quality		Aggregated Time-in-service (years)			Failure due to Demands			
OREDA		Good					Probability (γ)		MTTR (in hours)	
				Operational Time						
165			7.02E-03		16.5					
Installations	Population	Failure Data					Repair Data			
9	92	Nb. of Failures	MTTF (in years)	Failure Rate (per 10 ⁶ hours)			MTTR (in hours)	Active repair rate (per 10 ² hours)		
Severity Class	Failure Mode			Lower	λ	Upper		Lower	μ	Upper
Critical	Fail while running	22	7.5	10.28	15.19	21.69	31.0	2.18	3.23	4.61
	Fail to start	1	165.3	0.04	0.69	3.28	6.0	0.85	16.67	79.06
Degraded	All	29	5.7	14.33	20.03	27.30	19.1	3.74	5.23	7.12

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Appendix 2
Pumps/Reciprocating/Chemical injection

Data Source		Sample Quality		Aggregated Time-in-service (years)			Failure due to Demands			
OREDA		Satisfactory					Operational Time		Probability (γ)	
				21		7.02E-03		16.5		
				Installations	Population	Failure Data				
4	18	Nb. of Failures (*)	MTTF (in years)	Failure Rate (per 10 ⁶ hours)			MTTR (in hours)	Active repair rate (per 10 ² hours)		
Severity Class	Failure Mode			Lower	λ	Upper		Lower	μ	Upper
Critical	Fail while running	10	2.1	29.57	54.51	92.46	47.0	1.15	2.13	3.61
	Fail to start	0.7	29.9	0.01	3.82	21.30				
Degraded	All	9	2.3	25.59	49.06	85.61	45.0	1.16	2.22	3.88

Pumps/Rotary/All.

Data Source		Sample Quality		Aggregated Time-in-service (years)			Failure due to Demands			
OREDA		Satisfactory					Probability (γ)		MTTR (in hours)	
				Operational Time						
26			1.80E-03		56.1					
Installations	Population	Failure Data					Repair Data			
3	10	Nb. of Failures	MTTF (in years)	Failure Rate (per 10 ⁶ hours)			MTTR (in hours)	Active repair rate (per 10 ² hours)		
Severity Class	Failure Mode			Lower	λ	Upper		Lower	μ	Upper
Critical	Fail while running	15	1.7	41.38	67.14	103.38	8.0	7.71	12.50	19.25
	Fail to start	1	25.5	0.23	4.48	21.23	2.0	2.56	50.00	237.19
Degraded	All	23	1.1	70.36	102.94	145.84	2.3	29.11	42.59	60.34

2.4. Combustion engines

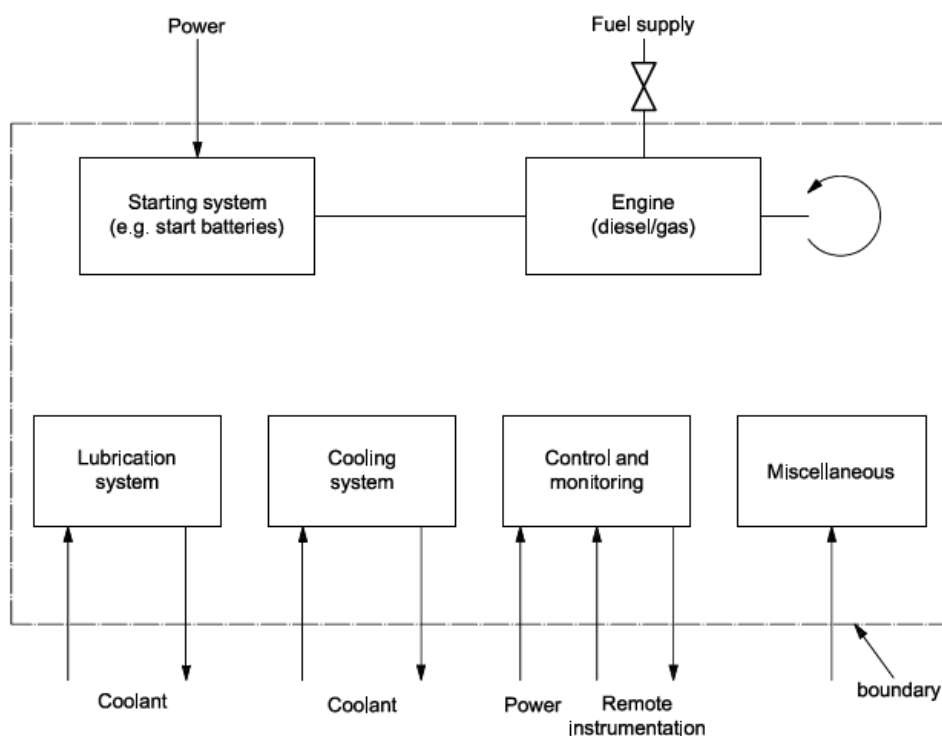


Figure 6: Boundary Definition - Combustion Engine

Combustion engines/All.

Data Source		Sample Quality		Aggregated Time-in-service (years)			Failure due to Demands			
OREDA		Satisfactory					Operational Time		Probability (γ)	
				40						
				Installations	Population	Failure Data				
39	82	Nb. of Failures	MTTF (in years)	Failure Rate (per 10 ⁶ hours)			MTTR (in hours)	Active repair rate (per 10 ² hours)		
Severity Class	Failure Mode			Lower	λ	Upper		Lower	μ	Upper
Critical	Fail while running	10	4.0	15.51	28.59	48.50	21.0	2.58	4.76	8.08
	Fail to start	10	4.0	15.51	28.59	48.50	11.0	4.93	9.09	15.42
Degraded	All	64	0.6	147.07	183.00	225.33	13.3	6.06	7.50	9.18

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Appendix 2
Combustion engines/Diesel engine

Data Source		Sample Quality		Aggregated Time-in-service (years)			Failure due to Demands			
OREDA		Satisfactory		Operational Time			Probability (γ)	MTTR (in hours)		
				18						
				Installations	Population	Failure Data				
33	50	Nb. of Failures	MTTF (in years)	Failure Rate (per 10 ⁶ hours)			MTTR (in hours)	Active repair rate (per 10 ² hours)		
Severity Class	Failure Mode			Lower	λ	Upper		Lower	μ	Upper
Critical	Fail while running	9	2.0	29.68	56.89	99.27	22.0	2.37	4.55	7.93
	Fail to start	4	4.5	8.64	25.28	57.86	16.0	2.13	6.25	14.30
Degraded	All	61	0.3	305.30	382.43	473.72	13.5	5.95	7.41	9.12

Combustion engines/Gas engine

Data Source		Sample Quality		Aggregated Time-in-service (years)			Failure due to Demands			
OREDA		Satisfactory					Probability (γ)		MTTR (in hours)	
				Operational Time						
22			2.60E-03		44.8					
Installations	Population	Failure Data					Repair Data			
15	32	Nb. of Failures	MTTF (in years)	Failure Rate (per 10 ⁶ hours)			MTTR (in hours)	Active repair rate (per 10 ² hours)		
Severity Class	Failure Mode			Lower	λ	Upper		Lower	μ	Upper
Critical	Fail while running	17	1.3	56.57	88.78	133.16	8.0	0.64	12.50	59.30
	Fail to start	8	2.7	20.79	41.78	75.38	7.0	6.22	14.29	28.20
Degraded	All	65	0.3	270.94	336.84	414.42	6.4	4.82	15.56	37.60

Combustion engines/Crude engine

Data Source		Sample Quality		Aggregated Time-in-service (years)			Failure due to Demands			
In-house data		Poor					Probability (γ)		MTTR (in hours)	
				Operational Time						
					2.80E-03		24.0			
Installations	Population	Failure Data								
		Nb. of Failures	MTTF (in years)	Failure Rate (per 10 ⁶ hours)			MTTR (in hours)	Active repair rate (per 10 ² hours)		
Severity Class	Failure Mode			Lower	λ	Upper		Lower	μ	Upper
Critical	Fail while running		1.0		113.78		44.0		0.02	
	Fail to start		2.3		50.57		32.0		0.03	
Degraded	All		0.1		764.85		32.0		0.03	

2.5. Turboexpanders

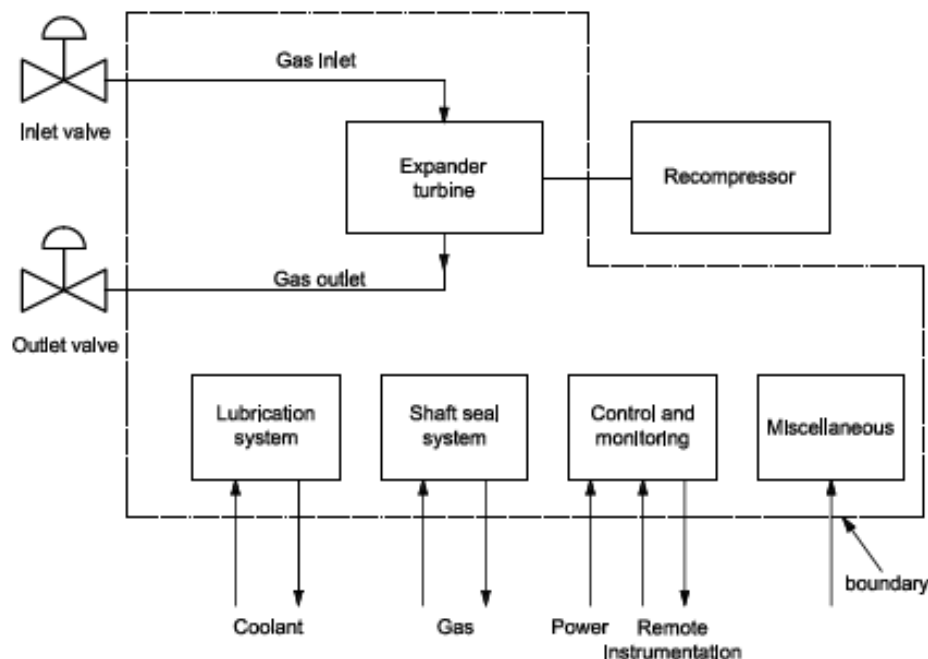


Figure 7: Boundary Definition - Turboexpanders

Turboexpanders/Centrifugal

Data Source		Sample Quality		Aggregated Time-in-service (years)			Failure due to Demands			
OREDA		Satisfactory					Probability (γ)		MTTR (in hours)	
				Operational Time						
50			1.00E-02		910.0					
Installations	Population	Failure Data					Repair Data			
6	15	Nb. of Failures	MTTF (in years)	Failure Rate (per 10 ⁶ hours)			MTTR (in hours)	Active repair rate (per 10 ² hours)		
Severity Class	Failure Mode			Lower	λ	Upper		Lower	μ	Upper
Critical	Fail while running	11	4.5	14.07	25.09	41.54	48.0	1.17	2.08	3.45
	Fail to start	1	50.0	0.12	2.28	10.82	910.0	0.01	0.11	0.52
Degraded	All	34	1.5	56.08	76.42	101.96	6.0	12.14	16.54	22.07

1.6: Steam turbines

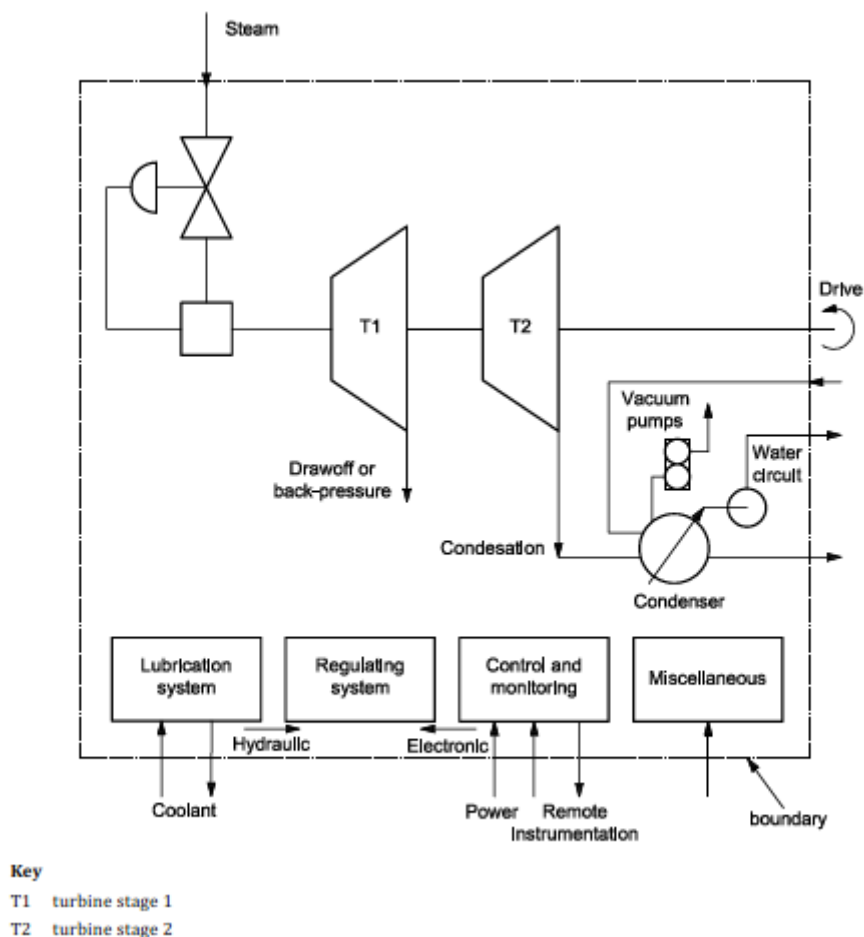


Figure 8: Boundary Definition - Steam turbines

(*) Zero failures estimator. Refer to 5.4.2

Steam turbines

Data Source		Sample Quality		Aggregated Time-in-service (years)			Failure due to Demands			
OREDA		Satisfactory		Operational Time			Probability (γ)		MTTR (in hours)	
				31						
Installations	Population	Failure Data					Repair Data			
3	6	Nb. of Failures (*)	MTTF (in years)	Failure Rate (per 10 ⁶ hours)			MTTR (in hours)	Active repair rate (per 10 ² hours)		
Severity Class	Failure Mode			Lower	λ	Upper		Lower	μ	Upper
Critical	Fail while running	6	5.2	9.58	22.00	43.41	10.0	4.36	10.00	19.74
	Fail to start	0.7	44.5	0.01	2.57	14.32				
Degraded	All	11	3.0	21.25	38.49	64.47	6.8	8.16	14.79	24.77

Appendix 3 Electrical equipment

3.1. Electric motors

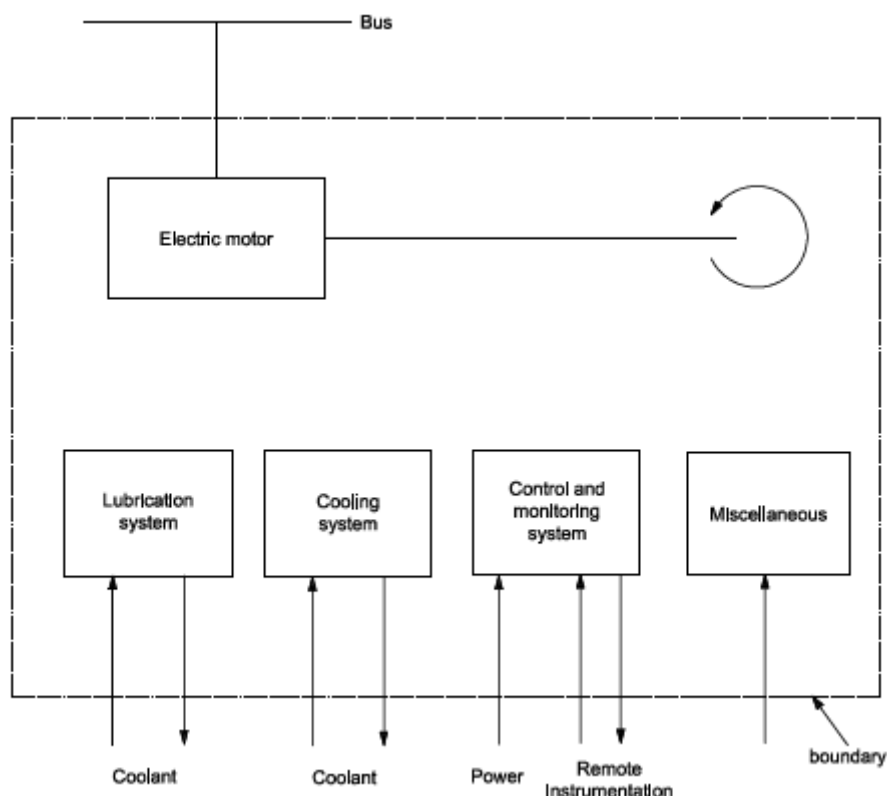


Figure 9: Boundary Definition - Electric motors

(*) Zero failures estimator. Refer to 5.4.2

Electric motors/AC/All

Data Source		Sample Quality		Aggregated Time-in-service (years)			Failure due to Demands			
OREDA		Good					Probability (γ)		MTTR (in hours)	
				Operational Time						
816			1.70E-03		19.2					
Installations	Population	Failure Data					Repair Data			
30	256	Nb. of Failures	MTTF (in years)	Failure Rate (per 10 ⁶ hours)			MTTR (in hours)	Active repair rate (per 10 ² hours)		
Severity Class	Failure Mode			Lower	λ	Upper		Lower	μ	Upper
Critical	Fail while running	76	10.7	8.71	10.64	12.87	24.0	3.42	4.17	5.03
	Fail to start	35	23.3	3.62	4.90	6.49	18.0	4.14	5.56	7.31
Degraded	All	120	6.8	14.36	16.80	19.55	10.7	8.02	9.38	10.90

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Appendix 3
Electric motors/AC/Design Power < 1 MW

Data Source		Sample Quality		Aggregated Time-in-service (years)			Failure due to Demands			
OREDA		Good					Operational Time		Probability (γ)	
				482		1.70E-03		19.2		
				Installations	Population	Failure Data				
16	154	Nb. of Failures	MTTF(in years)	Failure Rate (per 10 ⁶ hours)			MTTR (in hours)	Active repair rate (per 10 ² hours)		
Severity Class	Failure Mode			Lower	λ	Upper		Lower	μ	Upper
Critical	Fail while running	33	14.6	5.71	7.81	10.44	30.0	2.46	3.33	4.42
	Fail to start	15	32.2	2.19	3.55	5.46	8.0	7.71	12.50	19.25
Degraded	All	45	10.8	8.07	10.53	13.52	17.5	4.37	5.72	7.37

Electric motors/AC/ 1 MW $\leq$ Design Power $\leq$ 5 MW

Data Source		Sample Quality		Aggregated Time-in-service (years)			Failure due to Demands			
OREDA		Good					Probability (γ)		MTTR (in hours)	
				Operational Time						
235			1.70E-03		19.2					
Installations	Population	Failure Data					Repair Data			
21	77	Nb. of Failures	MTTF (in years)	Failure Rate (per 10 ⁶ hours)			MTTR (in hours)	Active repair rate (per 10 ² hours)		
Severity Class	Failure Mode			Lower	λ	Upper		Lower	μ	Upper
Critical	Fail while running	36	6.5	12.99	17.49	23.10	20.0	3.71	5.00	6.60
	Fail to start	12	19.6	3.36	5.83	9.45	33.0	1.83	3.03	4.74
Degraded	All	62	3.8	23.90	29.88	36.95	7.5	10.72	13.40	16.57

Electric motors/AC/Design Power > 5 MW

Data Source		Sample Quality		Aggregated Time-in-service (years)			Failure due to Demands			
OREDA		Satisfactory					Probability (γ)		MTTR (in hours)	
				Operational Time						
				63			1.70E-03		19.2	
Installations	Population	Failure Data					Repair Data			
8	20	Nb. of Failures	MTTF (in years)	Failure Rate (per 10 ⁶ hours)			MTTR (in hours)	Active repair rate (per 10 ² hours)		
Severity Class	Failure Mode			Lower	λ	Upper		Lower	μ	Upper
Critical	Fail while running	6	10.5	4.71	10.82	21.36	19.0	2.29	5.26	10.39
	Fail to start	8	7.9	7.18	14.43	26.03	9.0	5.53	11.11	20.05
Degraded	All	13	4.9	13.87	23.45	37.28	6.0	10.37	16.67	25.48