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Asse I - Obiettivo specifico 1a - Azione 1.1 (R&S)
Programma PBJMCM8
MIR: A0101.168
Importo del contributo 62%

IARIA

Isotta Fraschini Motori

Employing HDF5 File Format for Marine Engine Systems Data Storage

[ID: 60018]

a FINCANTIERI Company

Presenter: Giuseppe Giannino
Co-author: Michelangelo Tricarico and Andrea Orlando
Company: ISOTTA FRASCHINI MOTORI (Italy)
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ABOUT ME

2015 - POLYTECHNIC OF BARI
BACHELOR'S DEGREE IN ELECTRONIC & TELCO ENGINEERING

2017 – CORK INSTITUTE OF TECHNOLOGY
RESEARCH PROGRAM FOR MASTER'S DEGREE THESIS IN OPTICAL DEVICES

2018 – KAZAN NATIONAL RESEARCH TECHNICAL UNIVERSITY
RESEARCH PROGRAM FOR STUDENT EXCHANGE IN RADIOPHOTONIC, ANTENNA DESIGN AND MOBILE COMMUNICATIONS

2018 – POLYTECHNIC OF BARI
MASTER'S DEGREE IN TELCO ENGINEERING

2018÷2021 – ANGEL COMPANY (ITALY)
A.T.E. DESIGNER AND DEVELOPER

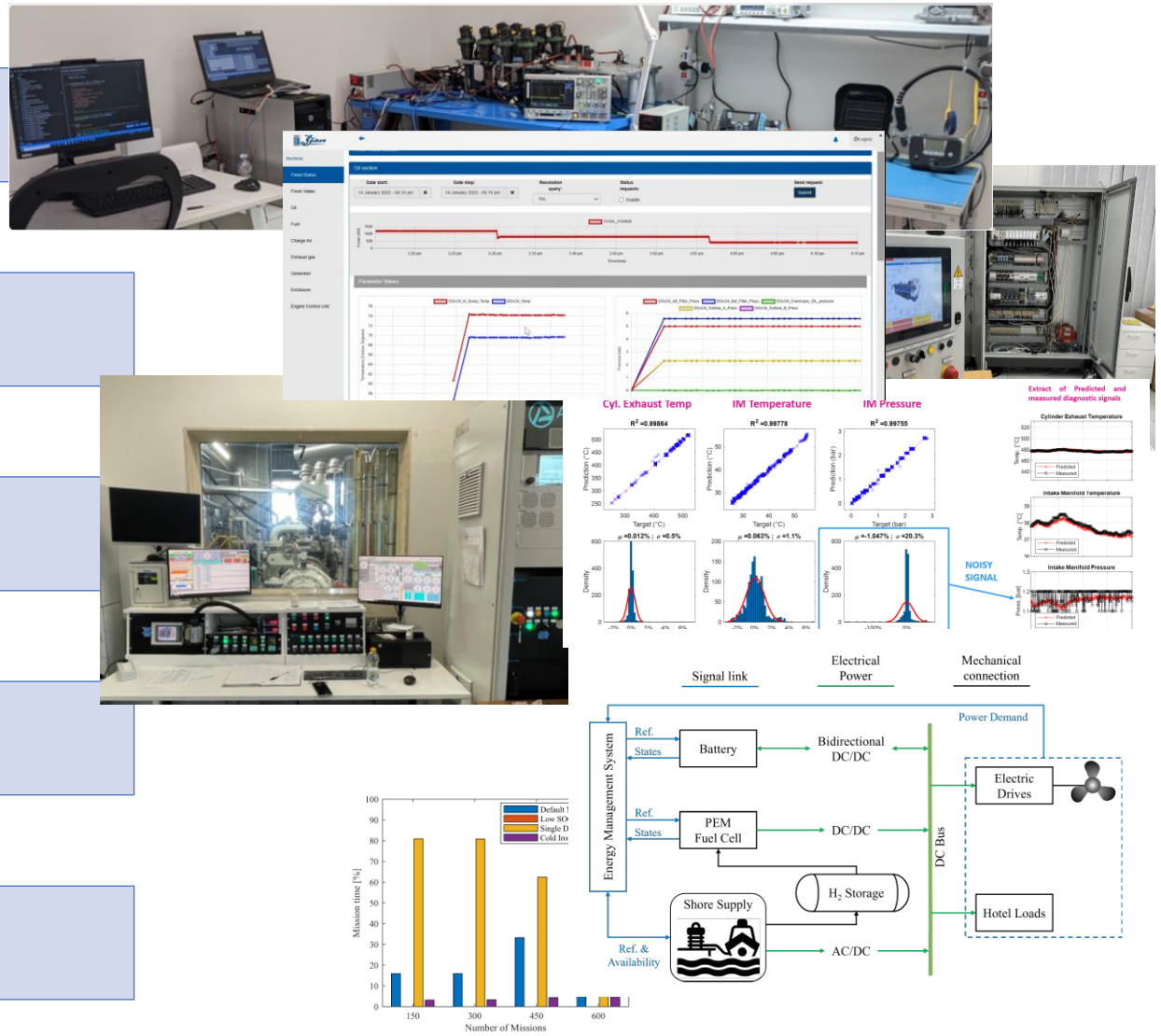
VALIDATION & INTEGRATION ENGINEER

2021÷today – ISOTTA FRASCHINI MOTORI
R&D AUTOMATION, CONTROL AND SUPERIVISION SYSTEM ENGINEER

HW/SW INTEGRATOR

MAIN TOPICS IN OUR R&D TEAM

- **IoT SYSTEMS FOR REMOTE ASSET MONITORING AND MANAGEMENT**
- **DATA ANALYSIS FOR PREDICTIVE PURPOSES**
- **DIGITAL TWINS FOR ICE AND PMS**
- **POWER AND ENERGY MANAGEMENT SYSTEMS (PMS AND EMS)**
- **INNOVATIVE POWER SOURCES (FUEL CELLS, GREEN FUELS, BATTERIES, ETC.)**



AGENDA

- INTRODUCTION
- HDF5 FILE FORMAT
- POPULAR COMMUNICATION PROTOCOLS IN MARINE ENGINE APPLICATIONS
- HDF5 and MARINE ENGINEs
- FILE BENCHMARKING
- HDF5 VISUALIZATION TOOL (IFM developments)
- CONCLUSIONS AND FUTURE WORK

INTRODUCTION [Ship Technology Transition]

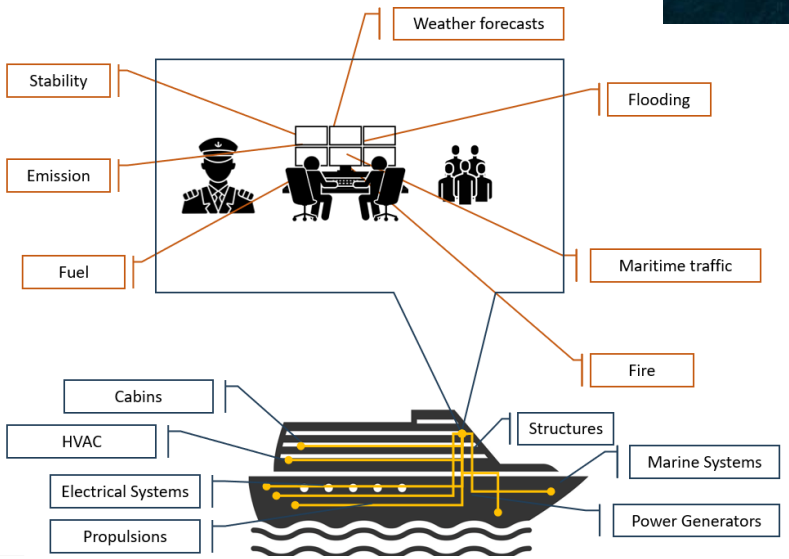
The smart ships of the future will require a strong effort for re-designing the current architectures to allow the implementation of new functionalities mostly based on data analysis and less on human mind.

Human Centered Approach

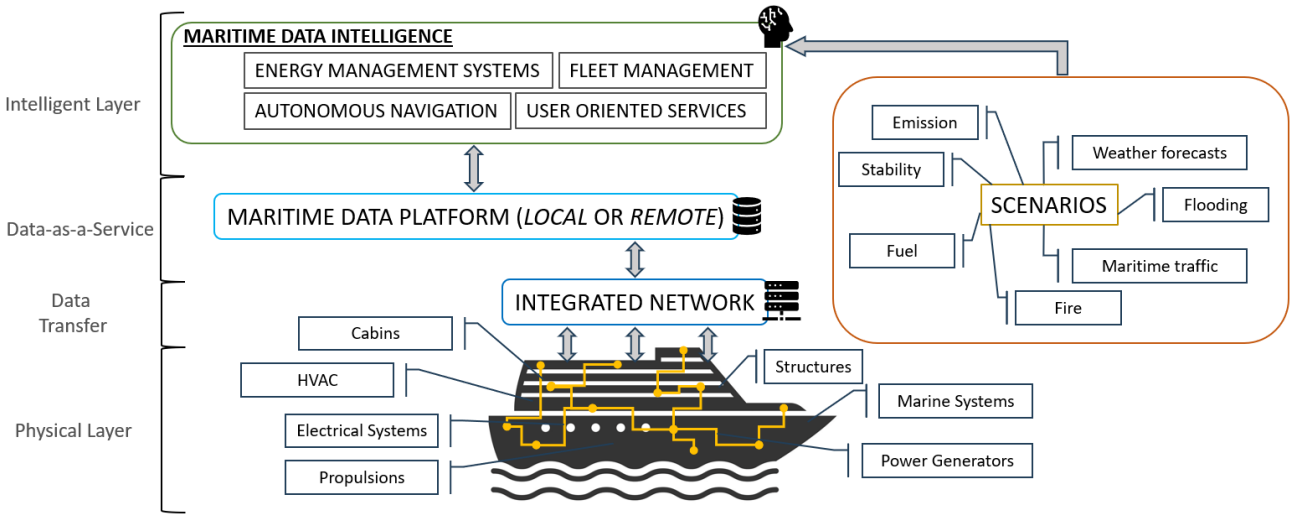
- Decisions constrained to human mind
- Large crew
- Lots of expertise among crew
- Low level of correlation between sub-systems information
- Poor optimization for energy resources, emissions, etc.

Data Driven Approach

- Decisions mainly based on data analysis by means of algorithms
- Minimized crew
- Less competencies requested among crew
- High correlation between data shared by sub-systems
- Higher asset optimization (energy resources, emissions, etc.) and safety improvements



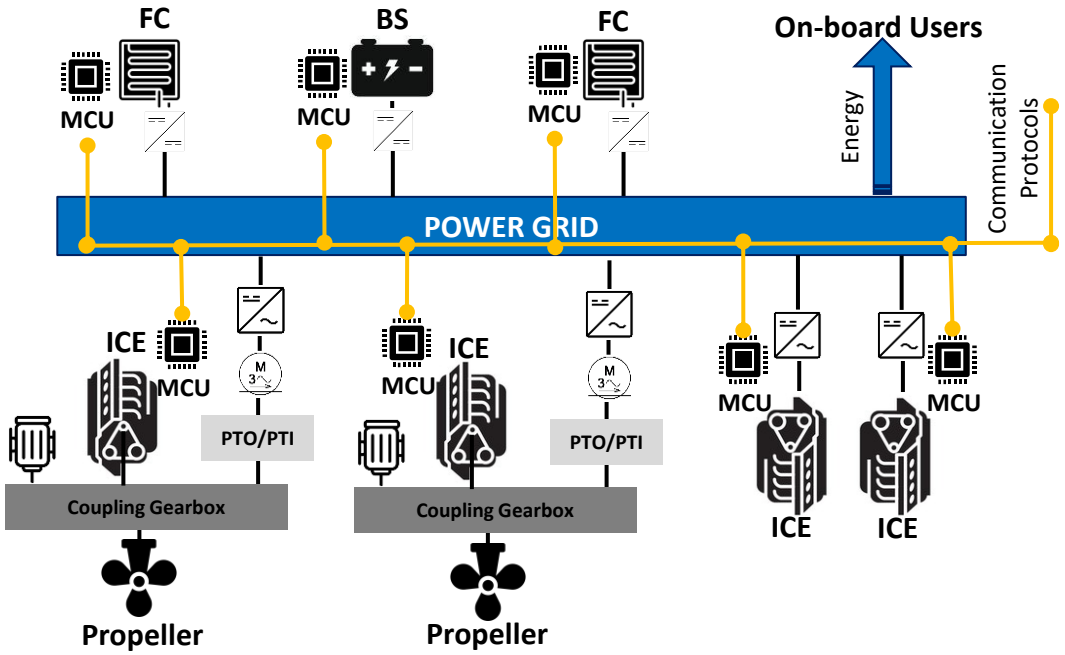
Ship Digital Transition



Isotta Fraschini Motori

INTRODUCTION [Energy Sources Sub-systems]

A complex hybrid energy system:



- Multiple energy sources → One common main DC bus and one energy source port for users
- Multiple MCU
- Multiple communication protocols
- Suitable for different operative conditions and loads requests

**ICE* = Internal Combustion engine
FC = Fuel Cell
BS = Battery stack
MCU = Main Control Unit

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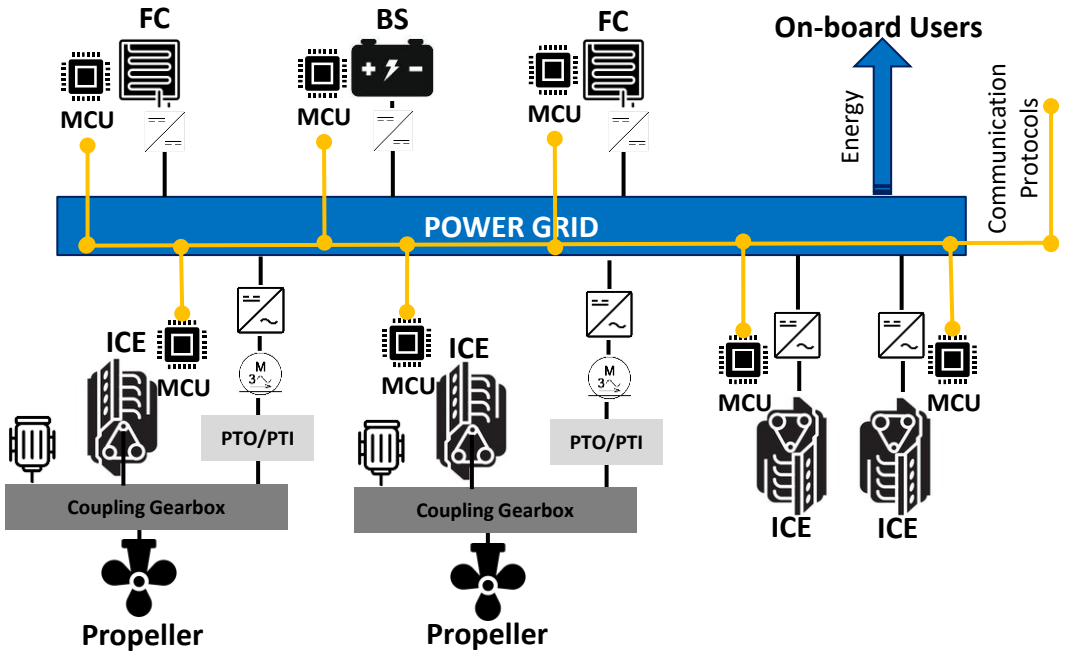

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- Multiple MCU
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- Suitable for different operative conditions and loads requests

**ICE* = Internal Combustion engine
FC = Fuel Cell
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Lots of DATA:

Great to be used … They just need to be combined and analyzed!

INTRODUCTION [Energy Sources Sub-systems]

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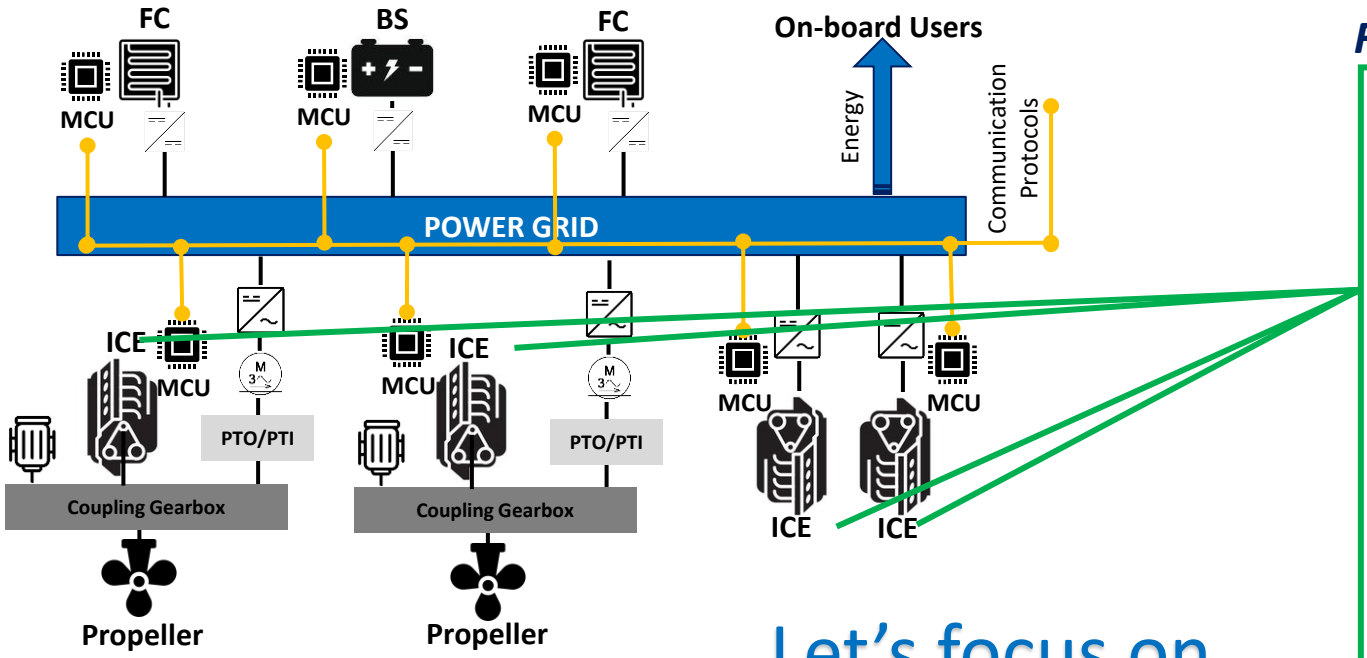
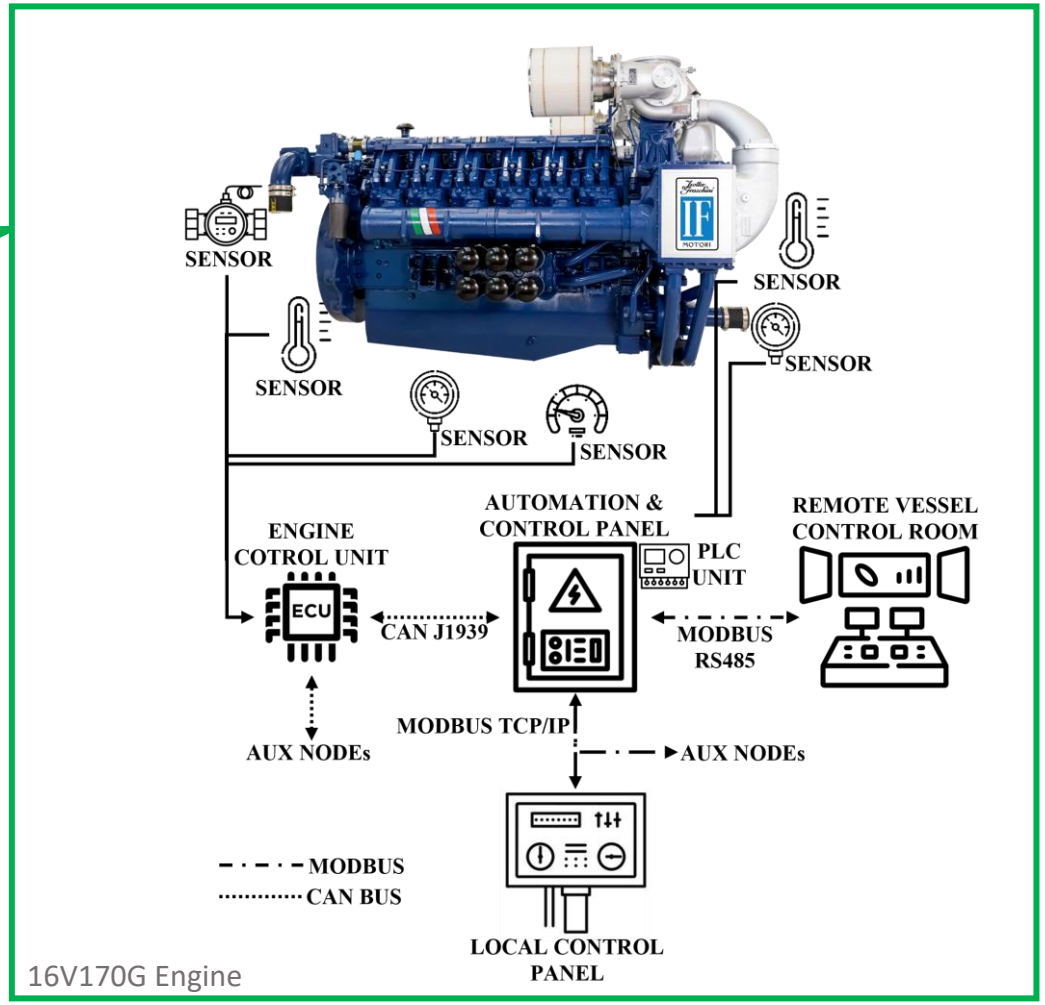


Let's focus on …

A typical ACS system for ICE designed by Isotta Fraschini Motori:



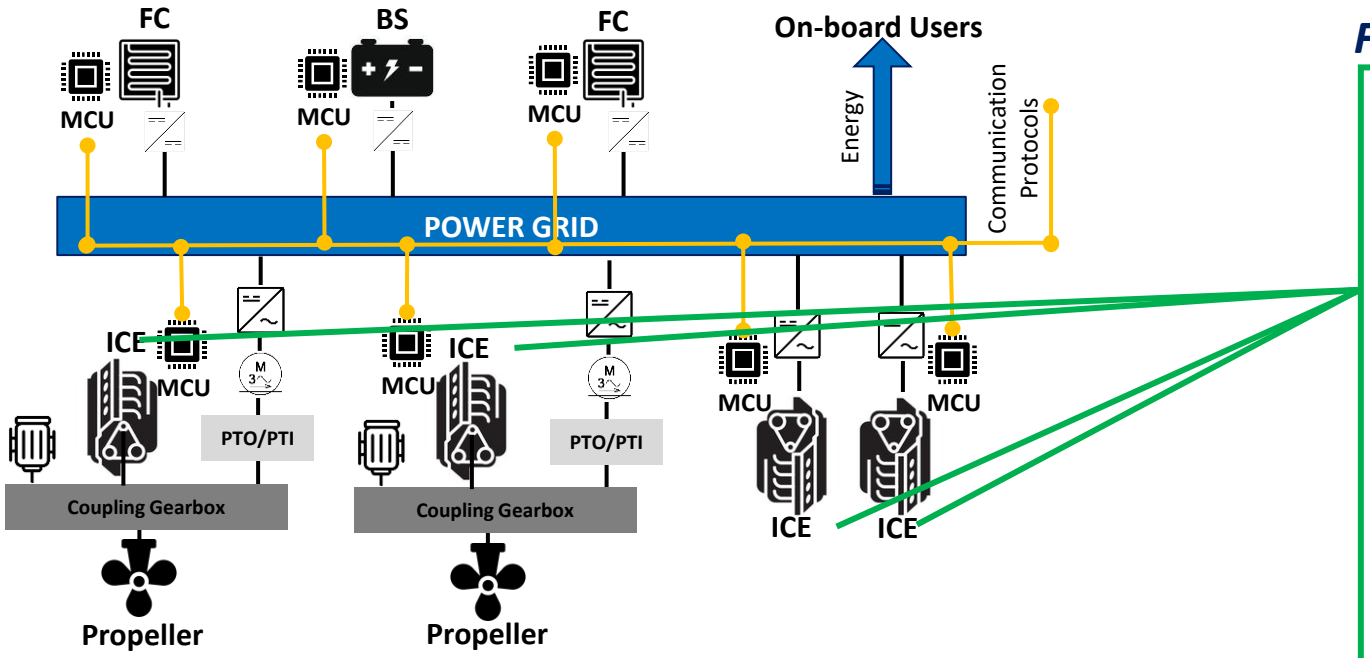
16V170G Engine

*ICE = Internal Combustion engine
FC = Fuel Cell
BS = Battery stack
MCU = Main Control Unit
ACS = Automation, Control and Supervision

Isotta Fraschini Motori

INTRODUCTION [Energy Sources Sub-systems]

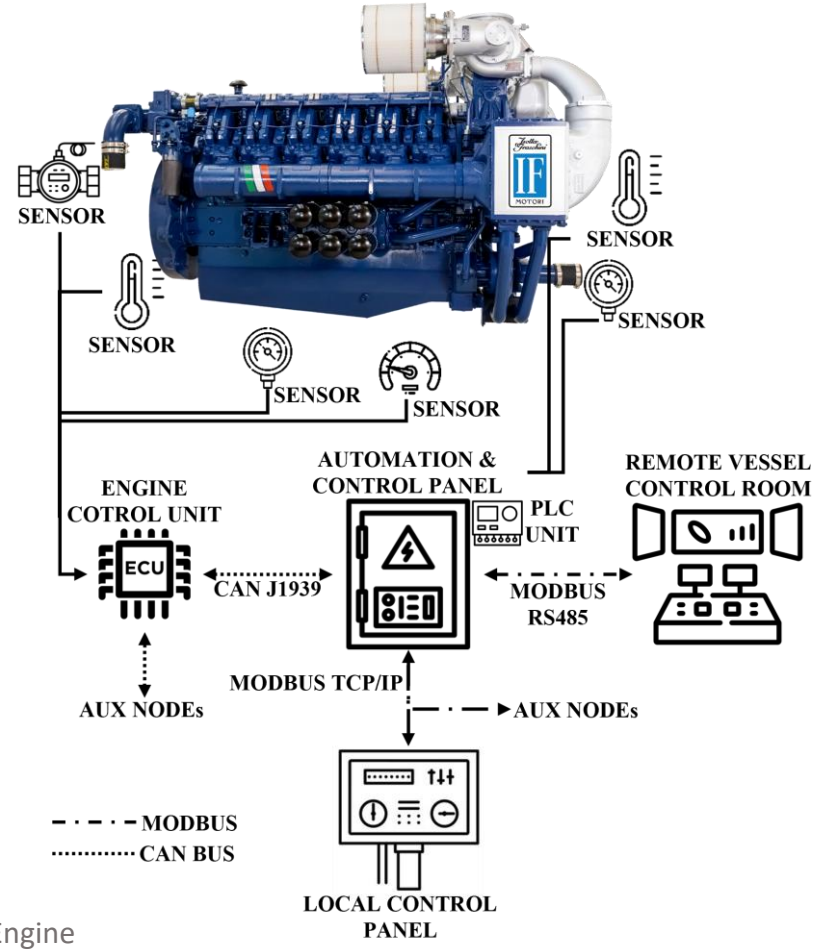
A complex hybrid energy system:



The approach could be exported to more complex systems

The idea is to aggregate all data acquired from communication protocols within one STANDARDIZED file format

A typical ACS system for ICE designed by Isotta Fraschini Motori:



16V170G Engine

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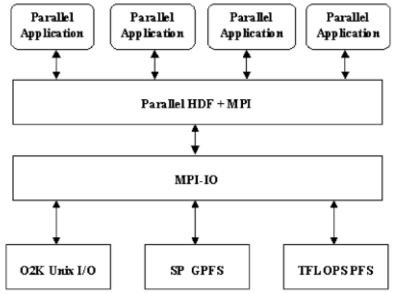
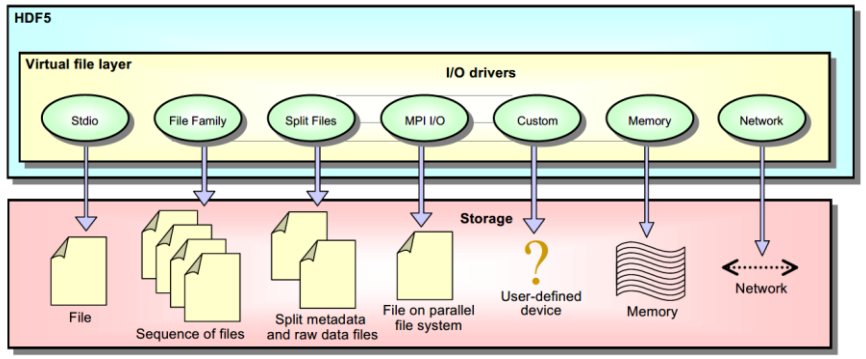
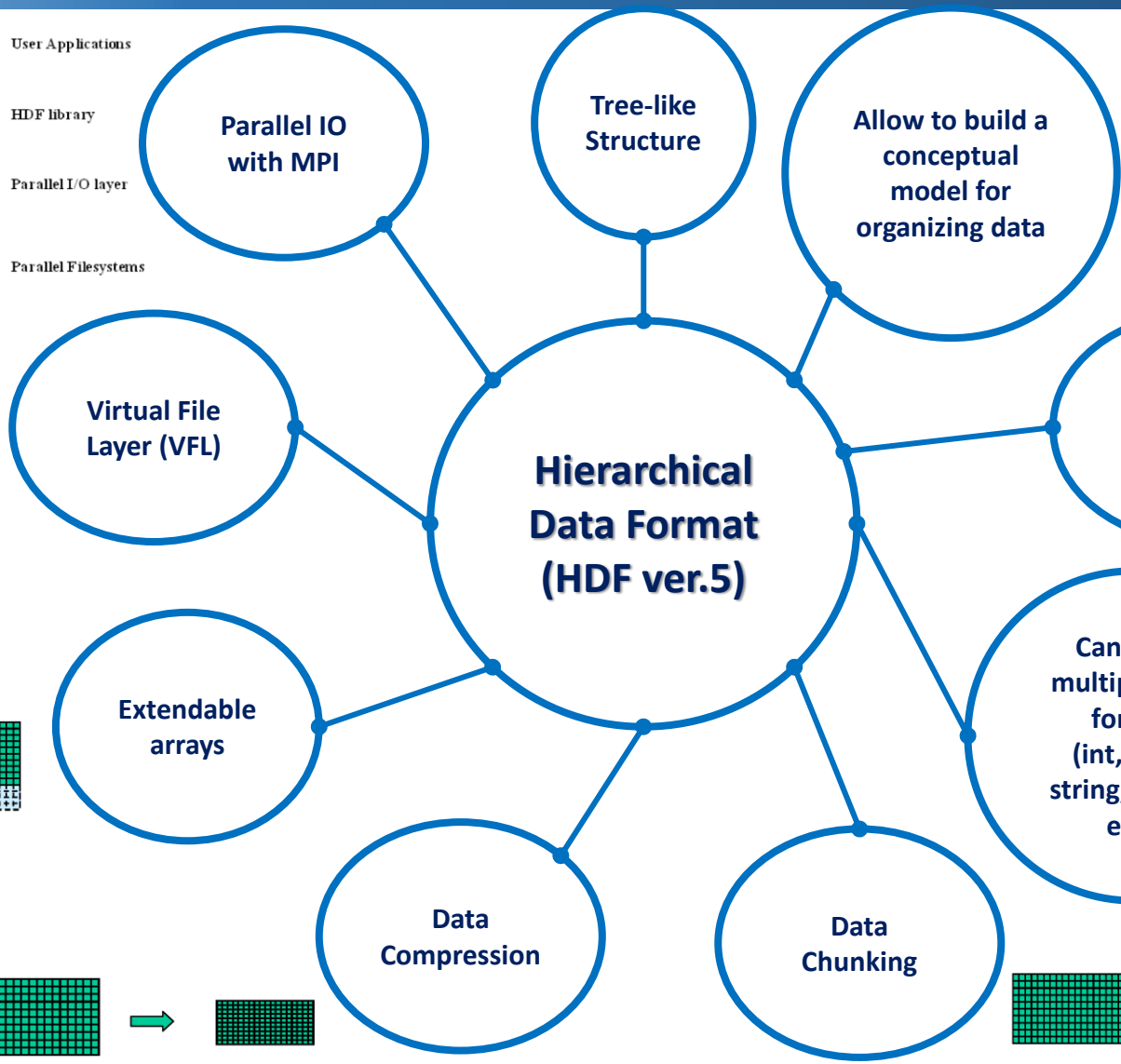
HDF5 FILE FORMAT

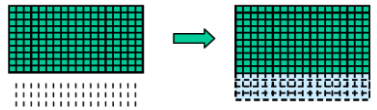
[…in a nutshell]



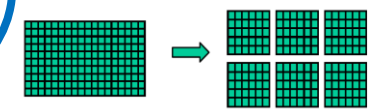




Extended in any direction



Improves efficiency and data transmission speed



Improves sub-setting access time

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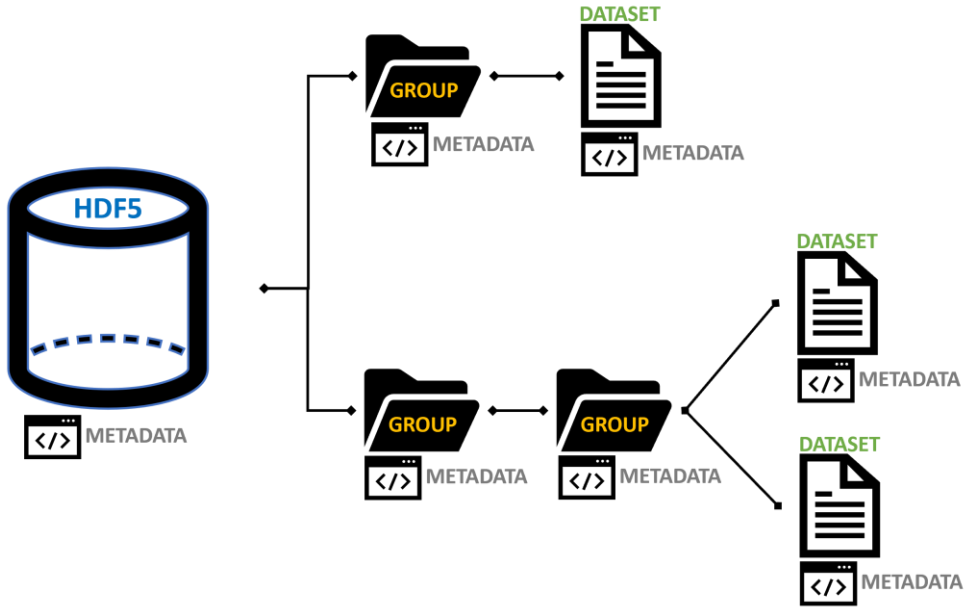
HDF5 FILE FORMAT

[…in a nutshell]

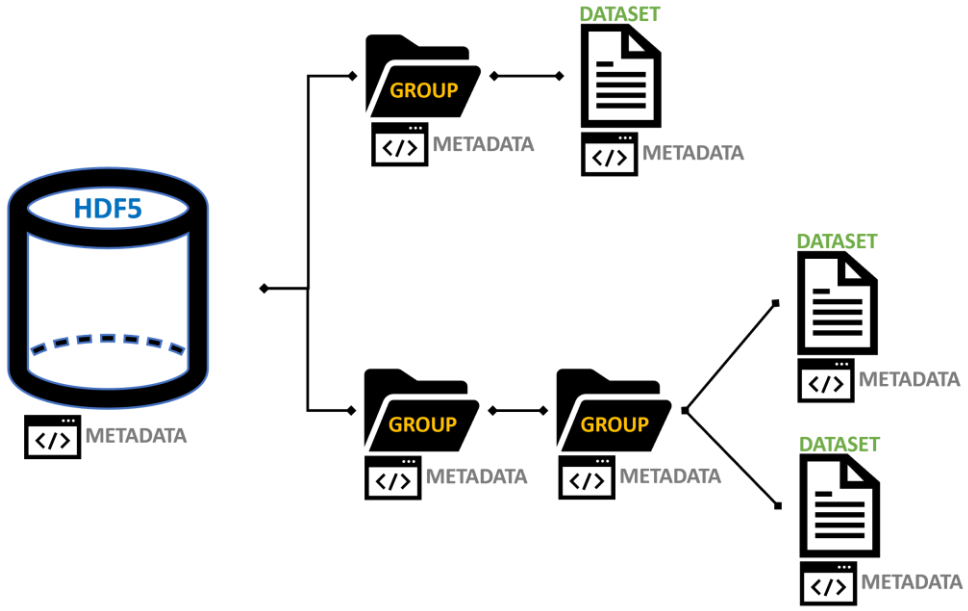


HDF5 has tree main objects:

- **GROUPS**
  - Overarching structures aimed to collect related objects
  - Always present a *Root Group*
- **DATASETS**
  - Include a multidimensional array of elements
  - Usually stored within groups
- **ATTRIBUTES**
  - Additional user-defined metadata associated to Group or Dataset
  - Paradigm *Key-Value*

HDF5 FILE FORMAT

[…in a nutshell]



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…Why HDF5 for our purposes?

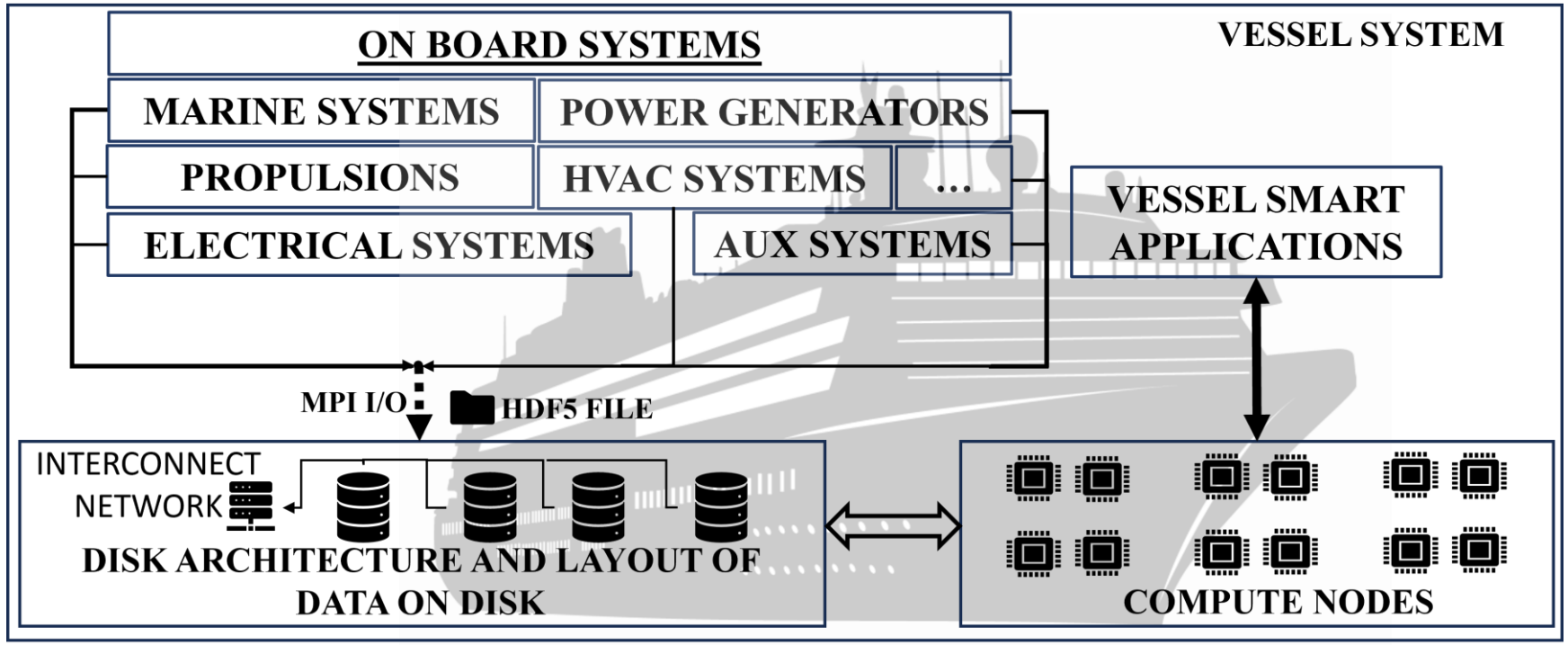
HDF5 FILE FORMAT

[…in a nutshell]

HDF5 is a great candidate for our purposes:

- Hierarchical data organization
- Attributes storage
- Compression
- Multi-dimensional capabilities
- Intuitive path-to-resource approach
- Parallel IO

High level application developers will love it!



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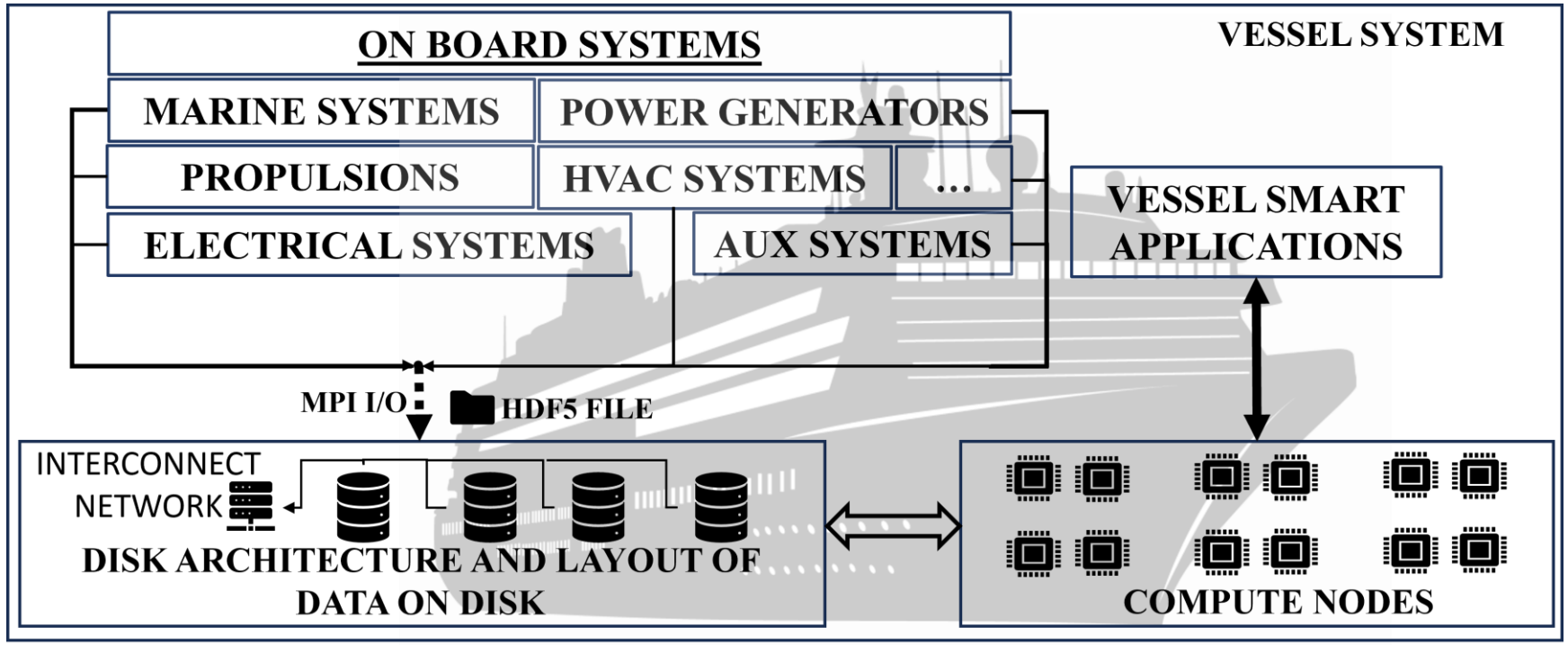

…How do we plan to use HDF5?

POPULAR COMMUNICATION PROTOCOLS IN MARINE ENGINE APPLICATIONS

[CAN bus…in a nutshell]

Controller Area Network (CAN) is/was/has:

- an International Standardization Organization (ISO) serial communication protocol
- Developed by BOSCH in 1991 as a multi-master broadcast system
- Max speed rate is 1 Mbps
- High Reliability

ISO/OSI LAYERS		CAN BUS STACK LAYERS	
7	APPLICATION	✓	Based on CAN version*
6	PRESENTATION	✗	
5	SESSION	✗	
4	TRANSPORT	✓	**
3	NETWORK	✓	**
2	DATA LINK	✓	ISO 11898
1	PHYSICAL	✓	ISO 11898

ISO-OSI CAN bus layers stack

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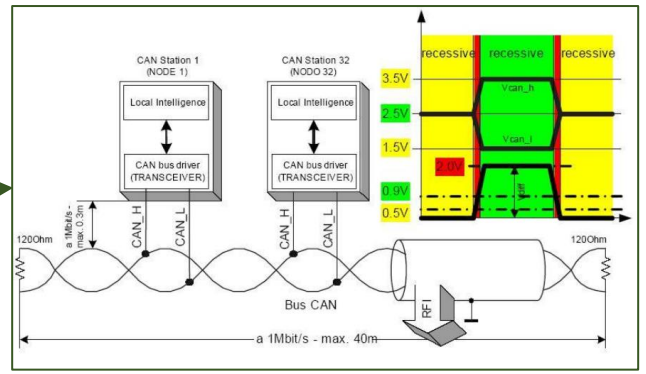

CAN Physical layer

- 2 wire bus
- Twisted pair cable
- Differential signal
- Strong **immunity to EM interferences**
- High resistance to transmission errors

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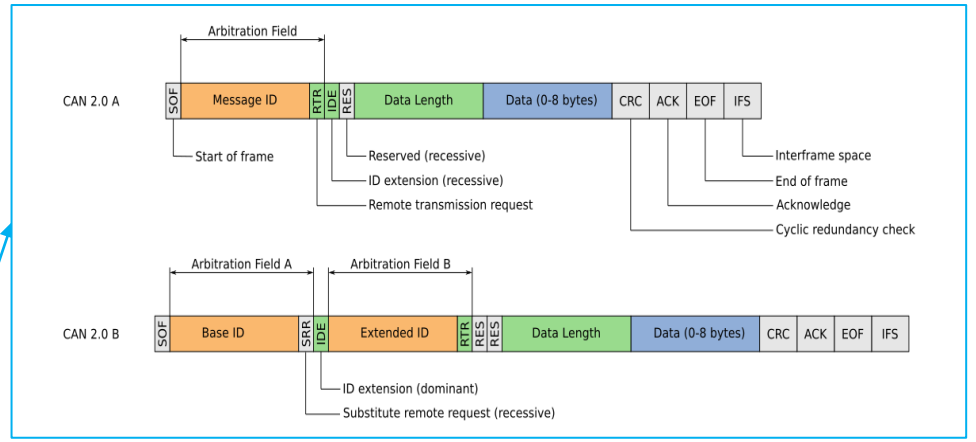
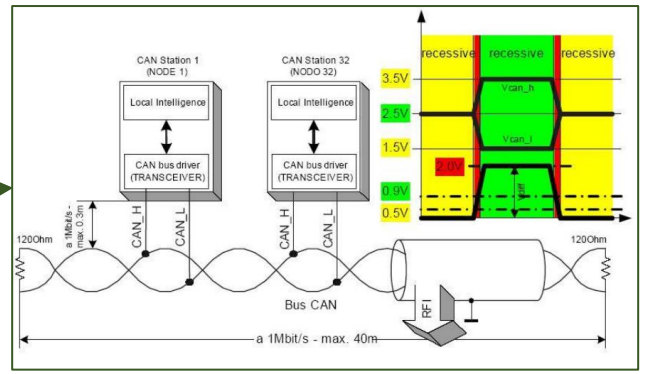


CAN Data Frame

- Two *Data Frame* variant are available from standard:
  - 2.0A (11-bit identifier)
  - 2.0B (29-bit identifier)
- The CAN FD (Flexible Data Rate) variant allows to increase data length and switching between rate



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4	TRANSPORT	✓	**
3	NETWORK	✓	**
2	DATA LINK	✓	ISO 11898
1	PHYSICAL	✓	ISO 11898

ISO-OSI CAN bus layers stack

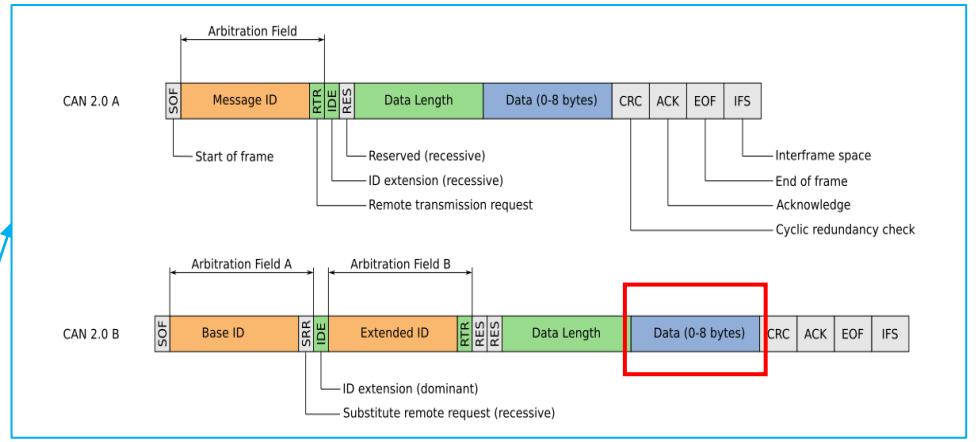
** optional for some CAN bus version

Different application layers are available on the market, such as CANOpen and CAN-J1939. The latter was released by Society of Automotive Engineers (SAE):

- It exploit CAN protocol lower layer
- Max data rate is fixed @ 250 Kbps
- Based on CAN 2.0B where are included: Message Priority, Sender, Type of data and standardization of specific data frame with their content.

SAE INTERNATIONAL J1939

CANopen



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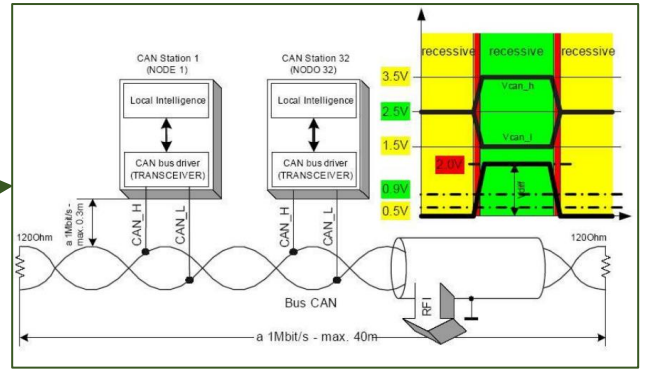

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POPULAR COMMUNICATION PROTOCOLS IN MARINE ENGINE APPLICATIONS

…We will come back on CAN bus protocol,
to see how it could work with HDF5!

POPULAR COMMUNICATION PROTOCOLS IN MARINE ENGINE APPLICATIONS

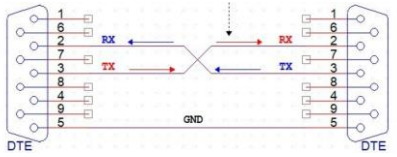
[MODBUS…in a nutshell]

MODBUS is:

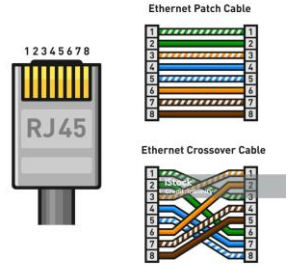
- A serial communication protocol
- Developed by Modicon in 1979 for Programmable Logic Controllers (PLC)
- A Master-Slave APPLICATION protocol
- Largely used in Industrial control systems

ISO/OSI LAYERS		MODBUS STACK LAYERS		
7	APPLICATION	✓	MODBUS APPLICATION LAYER	
6	PRESENTATION	✗		✗
5	SESSION	✗		✗
4	TRANSPORT	✓	MODBUS TCP	✗
3	NETWORK	✓	IP	✗
2	DATA LINK	✓	ETHERNET	✓ SERIAL LINE M/S
1	PHYSICAL	✓	ETHERNET ISO 8802-3	✓ EIA 485/232
			MODBUS TCP/IP	MODBUS ASCII/RTU

ISO-OSI MODBUS layers stack



Serial RS232 physical layer



Ethernet physical layer

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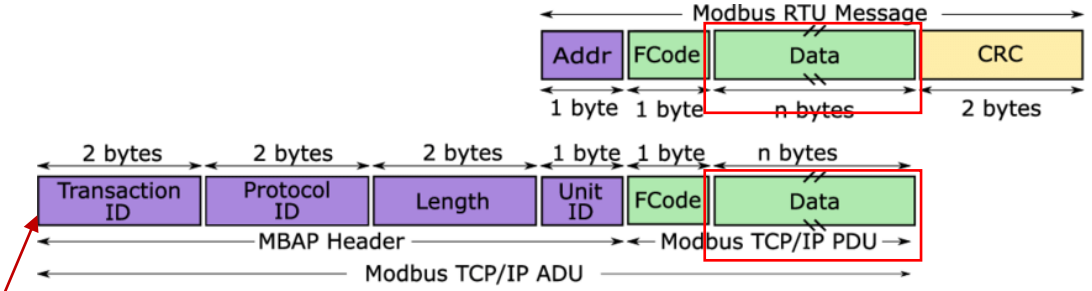

- The Function Code determines the type of action to be performed by the receiving device:
  - Read or Write from/on Slave
  - Coils (binary variable), physical Inputs or Internal Registers (16 bits or multiple) from Slave

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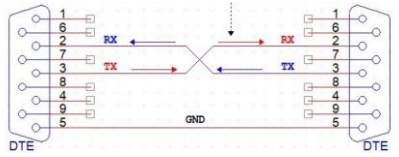
7	APPLICATION	✓	MODBUS APPLICATION LAYER	
6	PRESENTATION	✗		✗
5	SESSION	✗		✗
4	TRANSPORT	✓	MODBUS TCP	✗
3	NETWORK	✓	IP	✗
2	DATA LINK	✓	ETHERNET	✓ SERIAL LINE M/S
1	PHYSICAL	✓	ETHERNET ISO 8802-3	✓ EIA 485/232
			MODBUS TCP/IP	MODBUS ASCII/RTU

ISO-OSI MODBUS layers stack



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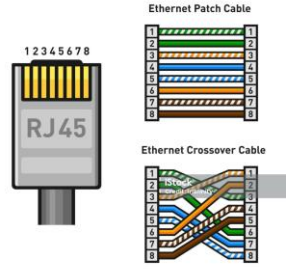
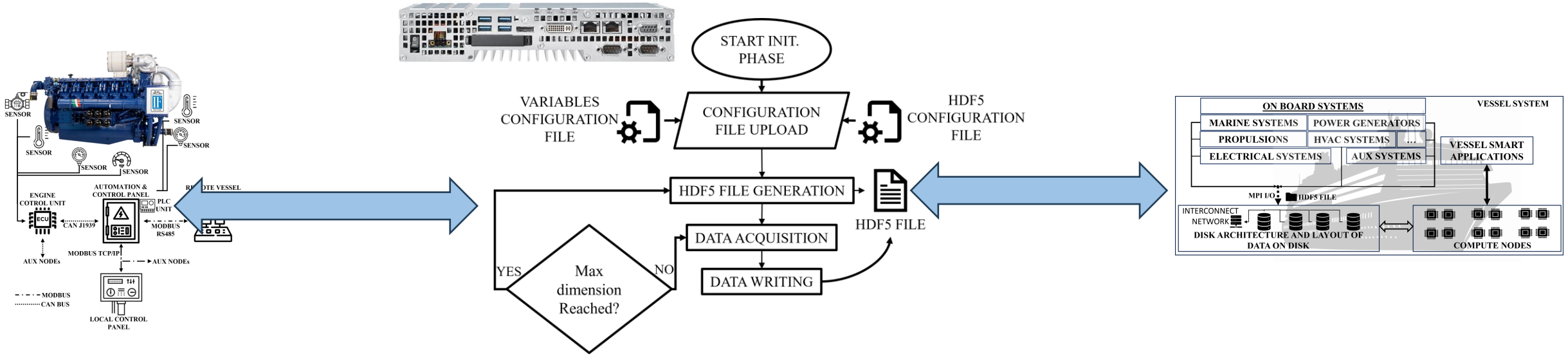


Ethernet physical layer

POPULAR COMMUNICATION PROTOCOLS IN MARINE ENGINE APPLICATIONS

… Interesting, and where HDF5 is? 

Data Gathering System



Based on **h5py Python library** which provides a high- and low-level interface to the HDF5 library:

- A complete wrapping of the HDF5 API (low-level)
- Access to HDF5 files, datasets and groups based on NumPy usage (high-level).

HDF5 and MARINE ENGINES *[TYPICAL VARIABLE CONFIGURATION FILES]*

CAN bus frames are described through a so called .dbc file:

CAN Messages

	Name	ID Decimal	ID HEX	PGN Decimal	PGN HEX	Frame Format	DLC	TX Node	Comment	
7	EEC1	418382849	18f00401	---	---	Extended	8	IFM_Engi...	Electroni...	
8	EC1	419357441	18fee301	---	---	Extended	39	IFM_Engi...	Engine_C...	
9	AT1IG2	419279873	18fdb401	---	---	Extended	8	IFM_Engi...	After_Tre...	
10	AT1OG2	419279617	18fdb301	---	---	Extended	8	IFM_Engi...	After_Tre...	
11	AT2OG2	419278849	18fdb001	---	---	Extended	8	IFM_Engi...	After_Tre...	
12	AT2IG2	419279105	18fdb101	---	---	Extended	8	IFM_Engi...	After_Tre...	
13	CA	254	000000fe	0	00000	J1939PGN	8	IFM_Engi...	Comman...	Ge
14	AMB	419362049	18fef501	---	---	Extended	8	IFM_Engi...	Ambient...	
15	EDC1	419377153	18ff3001	---	---	Extended	8	IFM_Engi...	EDC_Stat...	Ge
16	EDC2	419377409	18ff3101	---	---	Extended	8	IFM_Engi...	EDC_FFR...	Ge
17	EDC3	419377665	18ff3201	---	---	Extended	8	IFM_Engi...	EDC_Curr...	

Layout

Bit Positions

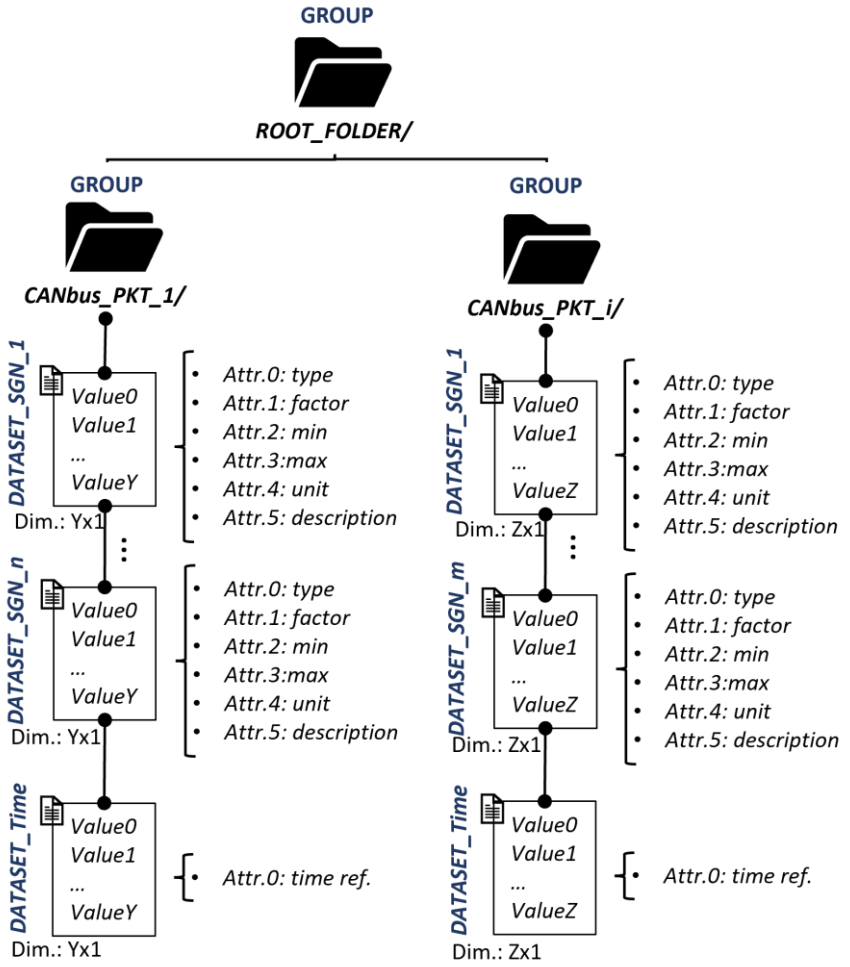
Signals of Selected CAN Message

	Name	Type	Byteorder	Mode	Bitpos	Length	Factor	Offset	Minimum	Maximum
1	SrcAddrssOfCtrlIngDvcFrEngCntrl	Unsigned	Intel	Signal	40	8	1	0	0	255
2	ActlEngPrcntTrqueHighResolution	Unsigned	Intel	Signal	4	4	0,125	0	0	0,875
3	EngDemandPercentTorque	Unsigned	Intel	Signal	56	8	1	-125	-125	125
4	EngStarterMode	Unsigned	Intel	Signal	48	4	1	0	0	15
5	EngSpeed	Unsigned	Intel	Signal	24	16	0,125	0	0	8031,88
6	ActualEngPercentTorque	Unsigned	Intel	Signal	16	8	1	-125	-125	125
7	DriversDemandEngPercentTorque	Unsigned	Intel	Signal	8	8	1	-125	-125	125
8	EngTorqueMode	Unsigned	Intel	Signal	0	4	1	0	0	15

MODBUS variables are usually mapped through a .csv file:

Information / Informazione		Automation / Automazione										
	*DGS= Diesel Generator Set **LCP=Local Control Panel	EXCHANGE DATA / SCAMBIO DATI										
Tag/Variabile	Reference/Riferimento	Type / Tipo	PLC	MODBUS	Bit	DIR	HW IN	HW OUT	MIN	MAX	MULT. / MOLT.	UNIT / UNITA'	DG CHANGE/ CAMBIO DG
DGxOil_In_Sump_Temp_CH_F	Channel fault or sensor fault/ Avaria canale o sensore TT04.02	BOOL	%M1589	%MW1012	12	OUT							
DGxOil_Turbine_A_Press_CH_F	Channel fault or sensor fault/ Avaria canale o sensore PT04.04	BOOL	%M1603	%MW1012	13	OUT							
DGxOil_Turbine_B_Press_CH_F	Channel fault or sensor fault/ Avaria canale o sensore PT04.05	BOOL	%M1602	%MW1012	14	OUT							
DGxOil_Alarms_Summary	Oil circuit alarms summary / Cumulativo allarmi circuito olio motore	BOOL	%M210	%MW1012	15	OUT							
DGxOil_Bef_Filter_Press	PT04.02: Oil pressure before filter / Pressione olio prima del filtro	WORD	%MW1514	%MW1013	-	OUT			0	100	0,1	bar	
DGxOil_Aft_Filter_Press	PT04.03: Oil pressure After filter / Pressione olio dopo del filtro	WORD	%MW1513	%MW1014	-	OUT			0	100	0,1	bar	
DGxOil_Temp	TT04.01: Lub oil bank inlet/ Pressione olio ingresso bancate	WORD	%MW1533	%MW1015	-	OUT			0	2000	0,1	°C	
DGxOil_In_Sump_Temp	TT04.02: Lub oil in sump temperature/ Temperatura olio in coppa	WORD	%MW1534	%MW1016	-	OUT			0	2000	0,1	°C	
DGxOil_Turbine_A_Press	PT04.04 Turbine A oil pressure / Pressione olio turbina bancata A	WORD	%MW1517	%MW1017	-	OUT			0	60	0,1	bar	
DGxOil_Turbine_B_Press	PT04.05 Turbine B oil pressure / Pressione olio turbina bancata B	WORD	%MW1571	%MW1018	-	OUT			0	60	0,1	bar	
DGxOil_Crankcase_OIL_pressure	PT04.06:Crankcase oil pressure/Pressione olio carter	WORD	%MW1596	%MW1019	-	OUT			-5	20	0,01	bar	

The proposed HDF5 tree-architecture for CAN bus J1939 is the following:



HDF5 and MARINE ENGINES

[HDF5 CAN bus TREE-ARCHITECTURE]

[A] Over CAN bus different frames with different frequencies can travel.

CAN Messages

	Name	ID Decimal	ID HEX	PGN Decimal	PGN HEX	Frame Format	DLC	TX Node	Comment
7	EEC1	418382849	18f00401	---	---	Extended	8	IFM_Engi...	El...
8	EC1	419357441	18fee301	---	---	Extended	39	IFM_Engi...	Engine_C...
9	AT1IG2	419279873	18fdb401	---	---	Extended	8	IFM_Engi...	Af...
10	AT1OG2	419279617	18fdb301	---	---	Extended	8	IFM_Engi...	After_Tre...
11	AT2OG2	419278849	18fdb001	---	---	Extended	8	IFM_Engi...	After_Tre...
12	AT2IG2	419279105	18fdb101	---	---	Extended	8	IFM_Engi...	After_Tre...
13	CA	254	000000fe	0	00000 J1939PGN		8	IFM_Engi...	Comman... Ge
14	AMB	419362049	18fef501	---	---	Extended	8	IFM_Engi...	Ambient...
15	EDC1	419377153	18ff3001	---	---	Extended	8	IFM_Engi...	EDC_Stat... Ge
16	EDC2	419377409	18ff3101	---	---	Extended	8	IFM_Engi...	EDC_FFR... Ge
17	EDC3	419377665	18ff3201	---	---	Extended	8	IFM_Engi...	EDC_Curr...

Layout

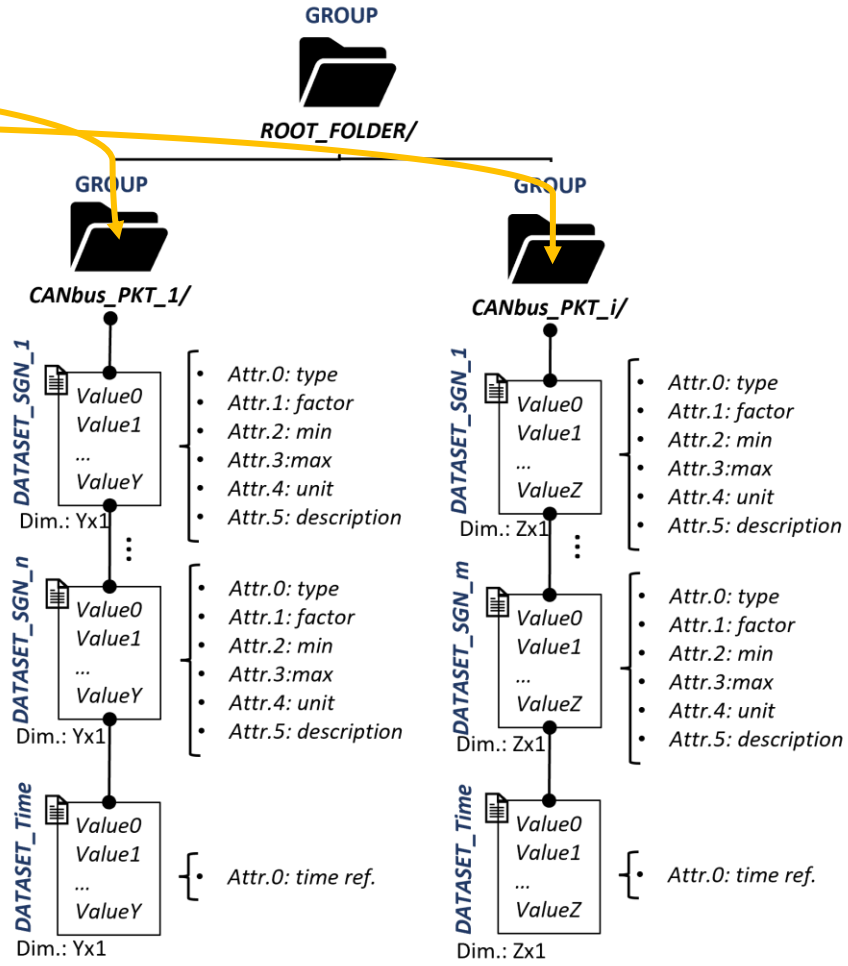
Bit Positions

Byte Number

Signals of Selected CAN Message

	Name	Type	Byteorder	Mode	Bitpos	Length	Factor	Offset	Minimum	Maximum
1	SrcAddrssOfCtrlIngDvcFrEngCntrl	Unsigned	Intel	Signal	40	8	1	0	0	255
2	ActlEngPrcntTrqueHighResolution	Unsigned	Intel	Signal	4	4	0,125	0	0	0,875
3	EngDemandPercentTorque	Unsigned	Intel	Signal	56	8	1	-125	-125	125
4	EngStarterMode	Unsigned	Intel	Signal	48	4	1	0	0	15
5	EngSpeed	Unsigned	Intel	Signal	24	16	0,125	0	0	8031,88
6	ActualEngPercentTorque	Unsigned	Intel	Signal	16	8	1	-125	-125	125
7	DriversDemandEngPercentTorque	Unsigned	Intel	Signal	8	8	1	-125	-125	125
8	EngTorqueMode	Unsigned	Intel	Signal	0	4	1	0	0	15

CAN bus data frame composition (J1939)



HDF5 and MARINE ENGINES

[HDF5 CAN bus TREE-ARCHITECTURE]

[A] Over CAN bus different frames with different frequencies can travel.

CAN Messages

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8	EC1	419357441	18fee301	---	---	Extended	39	IFM_Engi...	Engine_C...
9	AT1IG2	419279873	18fdb401	---	---	Extended	8	IFM_Engi...	Af...
10	AT1OG2	419279617	18fdb301	---	---	Extended	8	IFM_Engi...	After_Tre...
11	AT2OG2	419278849	18fdb001	---	---	Extended	8	IFM_Engi...	After_Tre...
12	AT2IG2	419279105	18fdb101	---	---	Extended	8	IFM_Engi...	After_Tre...
13	CA	254	000000fe	0	00000	J1939PGN	8	IFM_Engi...	Comman...
14	AMB	419362049	18fef501	---	---	Extended	8	IFM_Engi...	Ambient...
15	EDC1	419377153	18ff3001	---	---	Extended	8	IFM_Engi...	EDC_Stat...
16	EDC2	419377409	18ff3101	---	---	Extended	8	IFM_Engi...	EDC_FFR...
17	EDC3	419377665	18ff3201	---	---	Extended	8	IFM_Engi...	EDC_Curr...

Signals of Selected CAN Message

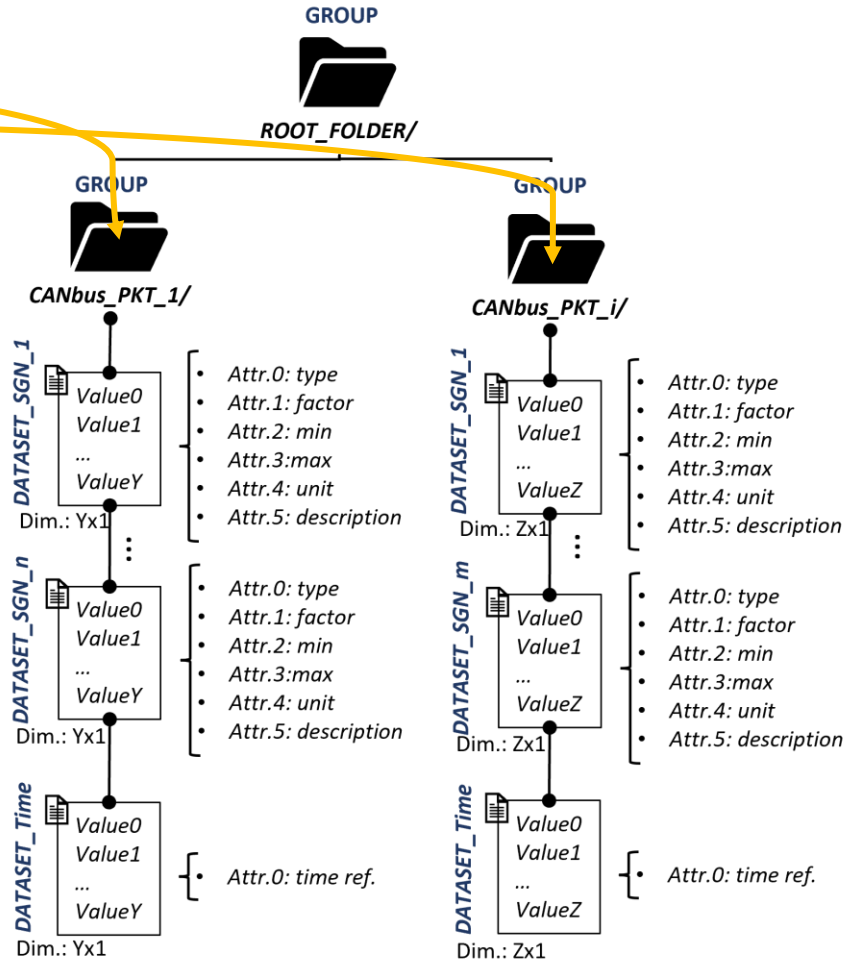
	Name	Type	Byteorder	Mode	Bitpos	Length	Factor	Offset	Minimum	Maximum
1	SrcAddrssOfCtrlIngDvcFrEngCntrl	Unsigned	Intel	Signal	40	8	1	0	0	255
2	ActlEngPrcntTrqueHighResolution	Unsigned	Intel	Signal	4	4	0,125	0	0	0,875
3	EngDemandPercentTorque	Unsigned	Intel	Signal	56	8	1	-125	-125	125
4	EngStarterMode	Unsigned	Intel	Signal	48	4	1	0	0	15
5	EngSpeed	Unsigned	Intel	Signal	24	16	0,125	0	0	8031,88
6	ActualEngPercentTorque	Unsigned	Intel	Signal	16	8	1	-125	-125	125
7	DriversDemandEngPercentTorque	Unsigned	Intel	Signal	8	8	1	-125	-125	125
8	EngTorqueMode	Unsigned	Intel	Signal	0	4	1	0	0	15

Layout

Bit Positions

Byte Number

CAN bus data frame composition (J1939)

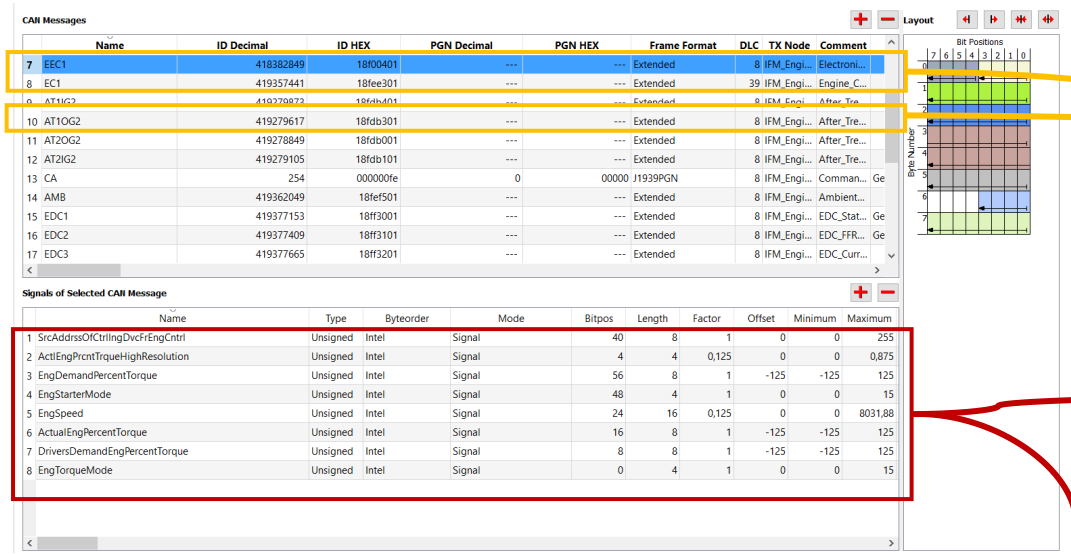


HDF5 and MARINE ENGINES

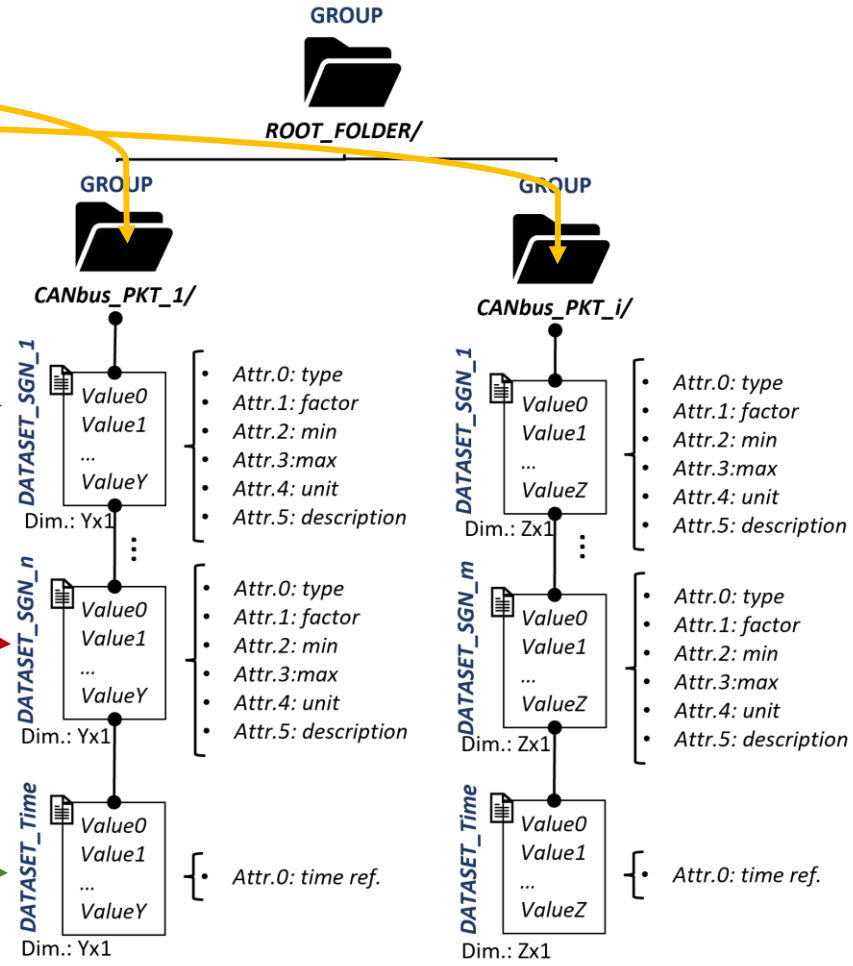
[HDF5 CAN bus TREE-ARCHITECTURE]

[A] Over CAN bus different frames with different frequencies can travel.

[B] Each CAN frame is filled with its own Data (called in J1939: SIGNALS)



CAN bus data frame composition (J1939)



HDF5 and MARINE ENGINES

[HDF5 CAN bus TREE-ARCHITECTURE]

[A] Over CAN bus different frames with different frequencies can travel.

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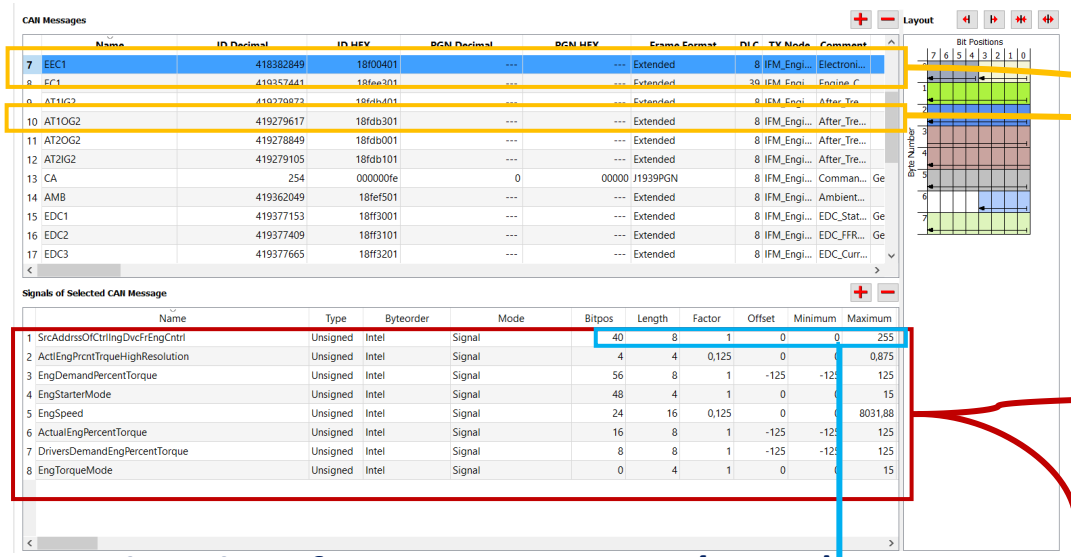
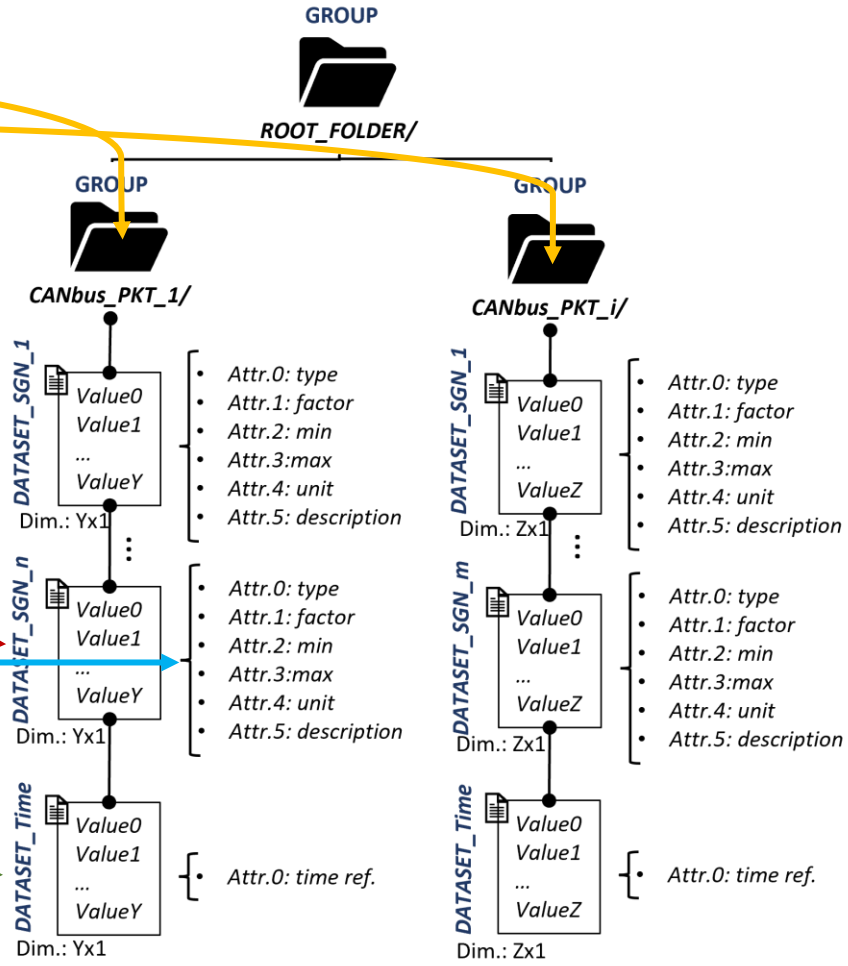


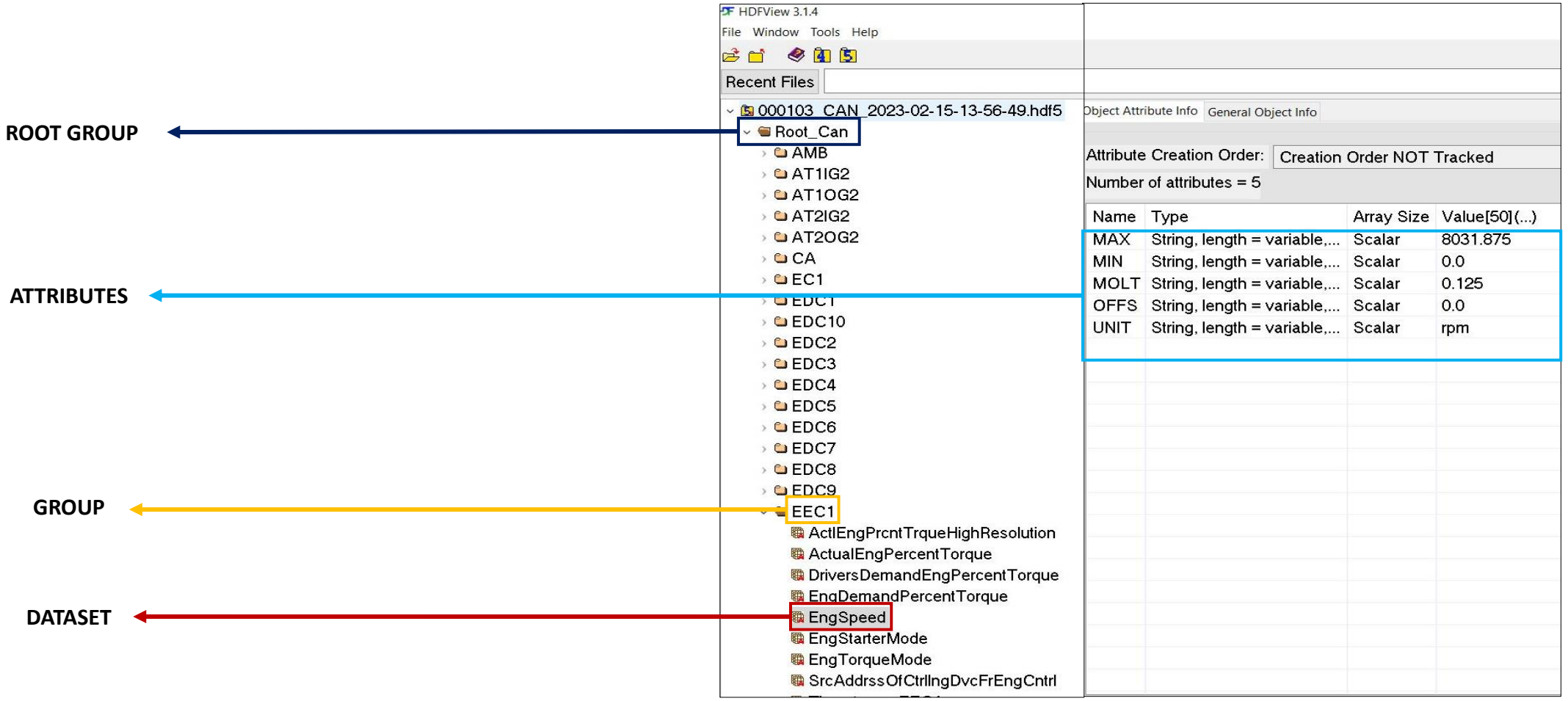
CAN bus data frame composition (J1939)

[C] Each signal has its own properties that can be stored as ATTRIBUTES within HDF5 file.

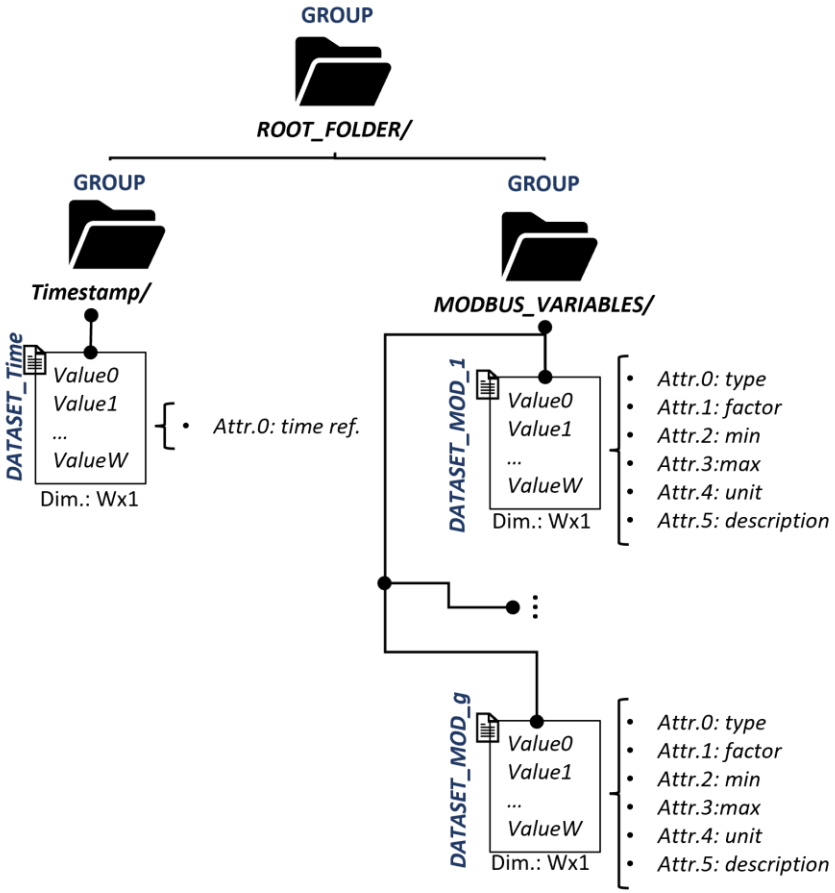


HDF5 and MARINE ENGINES [HDF5 CAN bus TREE-ARCHITECTURE]

How the HDF5 CAN bus file appears within HDFView (open-source software)



The proposed HDF5 tree-architecture for MODBUS is the following:



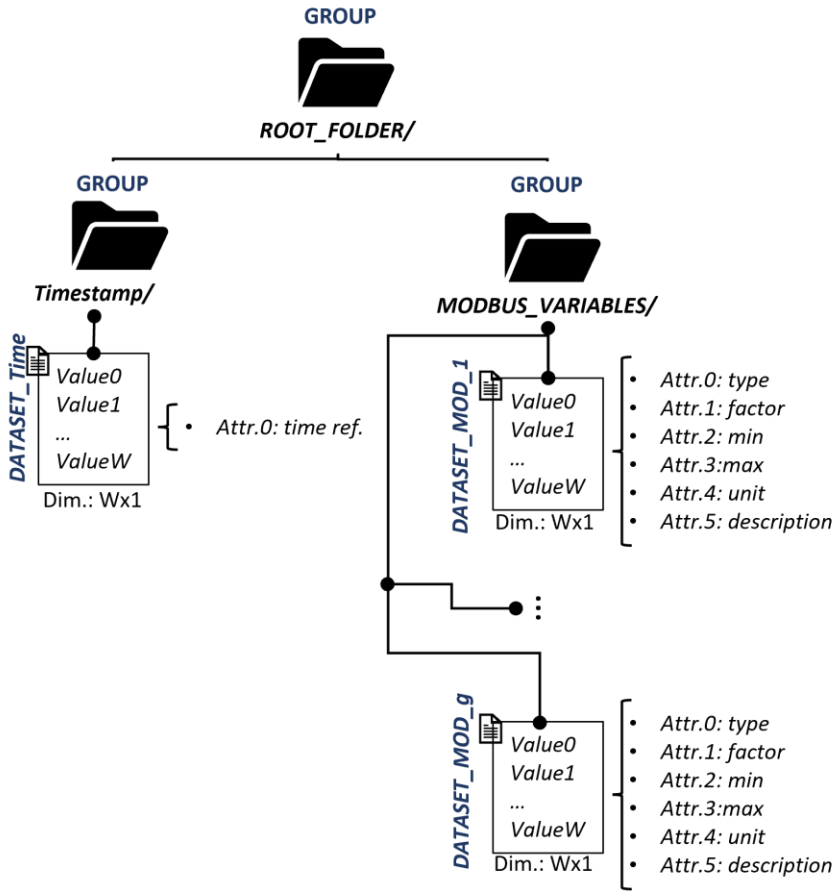
HDF5 and MARINE ENGINES

[HDF5 MODBUS TREE-ARCHITECTURE]

Information / Informazione		Automation / Automazione										
	*DGS= Diesel Generator Set **LCP=Local Control Panel	EXCHANGE DATA / SCAMBIO DATI										
Tag/Variabile	Reference/Riferimento	Type / Tipo	PLC	MODBUS	Bit	DIR	HW IN	HW OUT	MIN	MAX	MULT. / MOLT.	UNIT / UNITA'	DG CHANGE/ CAMBIO DG
DGxOil_In_Sump_Temp_CH_F	Channel fault or sensor fault/ Avaria canale o sensore TT04.02	BOOL	%M1589	%MW1012	12	OUT							
DGxOil_Turbine_A_Press_CH_F	Channel fault or sensor fault/ Avaria canale o sensore PT04.04	BOOL	%M1603	%MW1012	13	OUT							
DGxOil_Turbine_B_Press_CH_F	Channel fault or sensor fault/ Avaria canale o sensore PT04.05	BOOL	%M1602	%MW1012	14	OUT							
DGxOil_Alarms_Summary	Oil circuit alarms summary / Cumulativo allarmi circuito olio motore	BOOL	%M210	%MW1012	15	OUT							
DGxOil_Bef_Filter_Press	PT04.02: Oil pressure before filter / Pressione olio prima del filtro	WORD	%MW1514	%MW1013	-	OUT			0	100	0,1	bar	
DGxOil_Aft_Filter_Press	PT04.03: Oil pressure After filter / Pressione olio dopo del filtro	WORD	%MW1513	%MW1014	-	OUT			0	100	0,1	bar	
DGxOil_Temp	TT04.01: Lub oil bank inlet/ Pressione olio ingresso bancate	WORD	%MW1533	%MW1015	-	OUT			0	2000	0,1	°C	
DGxOil_In_Sump_Temp	TT04.02: Lub oil in sump temperature/ Temperatura olio in coppa	WORD	%MW1534	%MW1016	-	OUT			0	2000	0,1	°C	
DGxOil_Turbine_A_Press	PT04.04 Turbine A oil pressure / Pressione olio turbina bancata A	WORD	%MW1517	%MW1017	-	OUT			0	60	0,1	bar	
DGxOil_Turbine_B_Press	PT04.05 Turbine B oil pressure / Pressione olio turbina bancata B	WORD	%MW1571	%MW1018	-	OUT			0	60	0,1	bar	
DGxOil_Crankcase_OIL_pressure	PT04.06:Crankcase oil pressure/Pressione olio carter	WORD	%MW1596	%MW1019	-	OUT			-5	20	0,01	bar	

MODBUS variables list

[A] All MODBUS memory is read at the same time so just one time reference sample is needed to be stored.



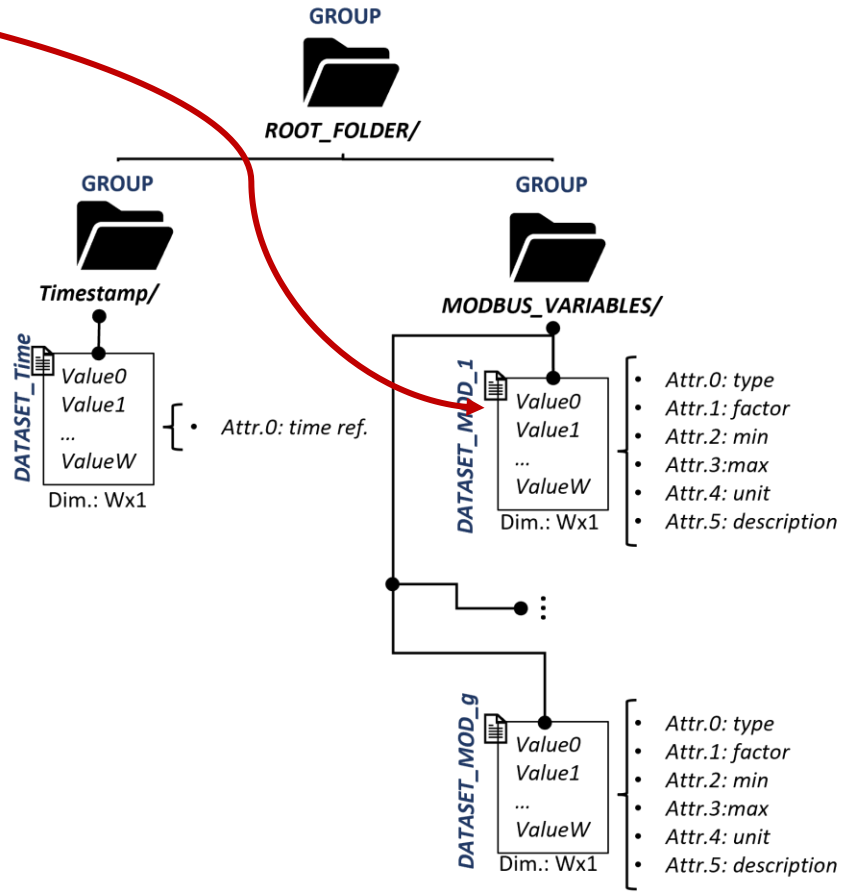
HDF5 and MARINE ENGINES [HDF5 MODBUS TREE-ARCHITECTURE]

Information / Informazione		Automation / Automazione										
	*DGS= Diesel Generator Set **LCP=Local Control Panel	EXCHANGE DATA / SCAMBIO DATI										
Tag/Variabile	Reference/Riferimento	Type / Tipo	PLC	MODBUS	Bit	DIR	HW IN	HW OUT	MIN	MAX	MULT. / MOLT.	UNIT / UNITA'	DG CHANGE/ CAMBIO DG
DGxOil_In_Sump_Temp_CH_F	Channel fault or sensor fault/ Avaria canale o sensore TT04.02	BOOL	%M1589	%MW1012	12	OUT							
DGxOil_Turbine_A_Press_CH_F	Channel fault or sensor fault/ Avaria canale o sensore PT04.04	BOOL	%M1603	%MW1012	13	OUT							
DGxOil_Turbine_B_Press_CH_F	Channel fault or sensor fault/ Avaria canale o sensore PT04.05	BOOL	%M1602	%MW1012	14	OUT							
DGxOil_Alarms_Summary	Oil circuit alarms summary / Cumulativo allarmi circuito olio motore	BOOL	%M210	%MW1012	15	OUT							
DGxOil_Bef_Filter_Press	PT04.02: Oil pressure before filter / Pressione olio prima del filtro	WORD	%MW1514	%MW1013	-	OUT			0	100	0,1	bar	
DGxOil_Aft_Filter_Press	PT04.03: Oil pressure After filter / Pressione olio dopo del filtro	WORD	%MW1513	%MW1014	-	OUT			0	100	0,1	bar	
DGxOil_Temp	TT04.01: Lub oil bank inlet/ Pressione olio ingresso bancate	WORD	%MW1533	%MW1015	-	OUT			0	2000	0,1	°C	
DGxOil_In_Sump_Temp	TT04.02: Lub oil in sump temperature/ Temperatura olio in coppa	WORD	%MW1534	%MW1016	-	OUT			0	2000	0,1	°C	
DGxOil_Turbine_A_Press	PT04.04 Turbine A oil pressure / Pressione olio turbina bancata A	WORD	%MW1517	%MW1017	-	OUT			0	60	0,1	bar	
DGxOil_Turbine_B_Press	PT04.05 Turbine B oil pressure / Pressione olio turbina bancata B	WORD	%MW1571	%MW1018	-	OUT			0	60	0,1	bar	
DGxOil_Crankcase_OIL_pressure	PT04.06:Crankcase oil pressure/Pressione olio carter	WORD	%MW1596	%MW1019	-	OUT			-5	20	0,01	bar	

MODBUS variables list

[A] All MODBUS memory are read at the same time so just one time reference sample is needed to be stored.

[B] Each variable has its own DATASET inside the same GROUP.



HDF5 and MARINE ENGINES

[HDF5 MODBUS TREE-ARCHITECTURE]

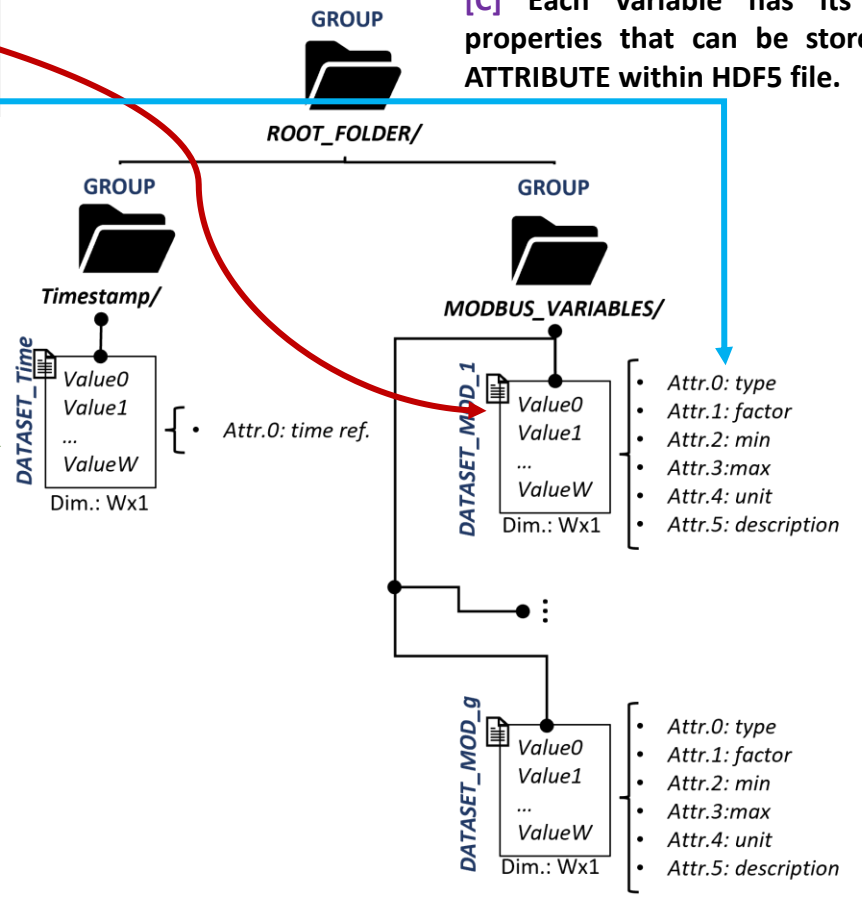
Information / Informazione		Automation / Automazione										
	*DGS= Diesel Generator Set **LCP=Local Control Panel	EXCHANGE DATA / SCAMBIO DATI										
Tag/Variabile	Reference/Riferimento	Type / Tipo	PLC	MODBUS	Bit	DIR	HW IN	HW OUT	MIN	MAX	MULT. / MOLT.	UNIT / UNITA'	DG CHANGE/ CAMBIO DG
DGxOil_In_Sump_Temp_CH_F	Channel fault or sensor fault/ Avaria canale o sensore TT04.02	BOOL	%M1589	%MW1012	12	OUT							
DGxOil_Turbine_A_Press_CH_F	Channel fault or sensor fault/ Avaria canale o sensore PT04.04	BOOL	%M1603	%MW1012	13	OUT							
DGxOil_Turbine_B_Press_CH_F	Channel fault or sensor fault/ Avaria canale o sensore PT04.05	BOOL	%M1602	%MW1012	14	OUT							
DGxOil_Alarms_Summary	Oil circuit alarms summary / Cumulativo allarmi circuito olio motore	BOOL	%M210	%MW1012	15	OUT							
DGxOil_Bef_Filter_Press	PT04.02: Oil pressure before filter / Pressione olio prima del filtro	WORD	%MW1514	%MW1013	-	OUT			0	100	0,1	bar	
DGxOil_Aft_Filter_Press	PT04.03: Oil pressure After filter / Pressione olio dopo del filtro	WORD	%MW1513	%MW1014	-	OUT			0	100	0,1	bar	
DGxOil_Temp	TT04.01: Lub oil bank inlet/ Pressione olio ingresso bancate	WORD	%MW1533	%MW1015	-	OUT			0	2000	0,1	°C	
DGxOil_In_Sump_Temp	TT04.02: Lub oil in sump temperature/ Temperatura olio in coppa	WORD	%MW1534	%MW1016	-	OUT			0	2000	0,1	°C	
DGxOil_Turbine_A_Press	PT04.04 Turbine A oil pressure / Pressione olio turbina bancata A	WORD	%MW1517	%MW1017	-	OUT			0	60	0,1	bar	
DGxOil_Turbine_B_Press	PT04.05 Turbine B oil pressure / Pressione olio turbina bancata B	WORD	%MW1571	%MW1018	-	OUT			0	60	0,1	bar	
DGxOil_Crankcase_OIL_pressure	PT04.06:Crankcase oil pressure/Pressione olio carter	WORD	%MW1596	%MW1019	-	OUT			-5	20	0,01	bar	

MODBUS variables list

[A] All MODBUS memory are read at the same time so just one time reference sample is needed to be stored.

[B] Each variable has its own DATASET inside the same GROUP.

[C] Each variable has its own properties that can be stored as ATTRIBUTE within HDF5 file.



HDF5 and MARINE ENGINES [HDF5 MODBUS TREE-ARCHITECTURE]

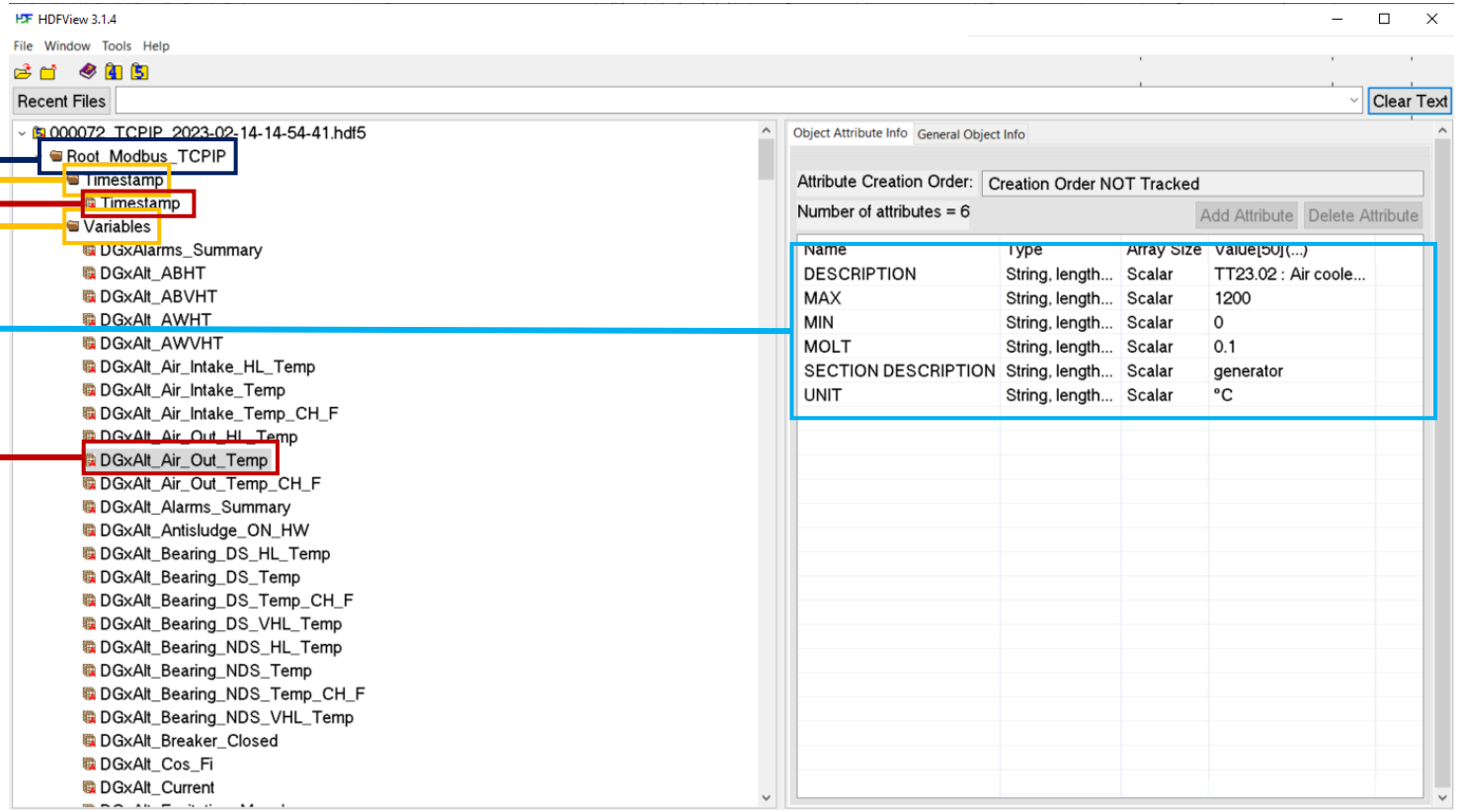
How the HDF5 MODBUS file appears within HDFView (open-source software)

ROOT GROUP

GROUP

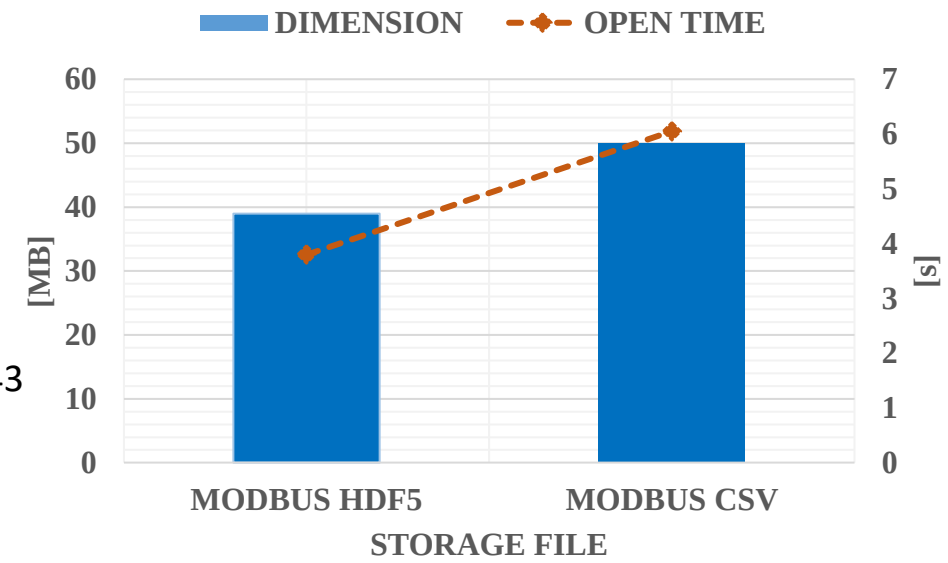
ATTRIBUTES

DATASET



FILE BENCHMARKING [PRELIMINARY RESULTS]

CSV Vs. HDF



Conditions*:

- *Protocol*: MODBUS TCP/IP
- *# of variables*: 457
- *Sample rate*: 3.5 sec
- *# of attributes per variables*: 6
- *# of samples stored per variable*: 17043
- *Acquisition duration*: 16 hours

Results:

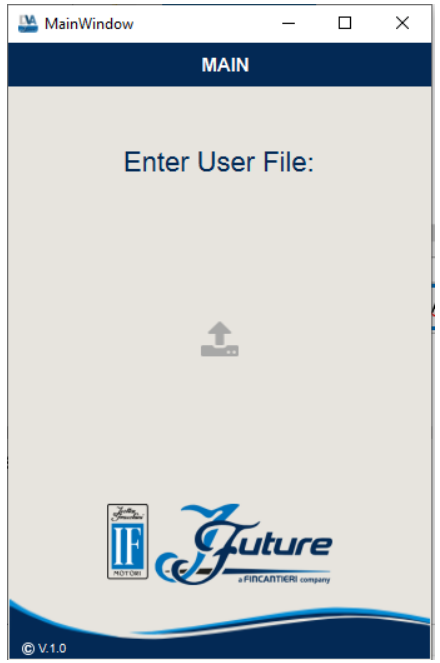
↓HDF5 File dimension: 20% less

↓HDF5 File opening time: about 2 seconds less

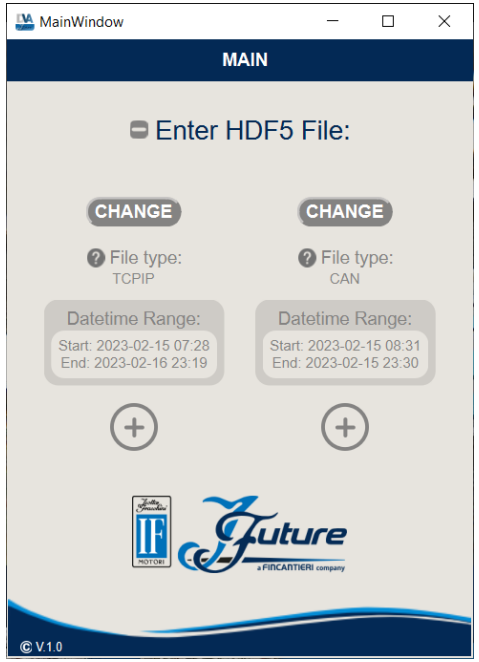
*Data acquired on a real asset (engine on board vessel) and considering some disconnection of the remote source node (PLC unit).

HDF5 VISUALIZATION TOOL [IFM development]

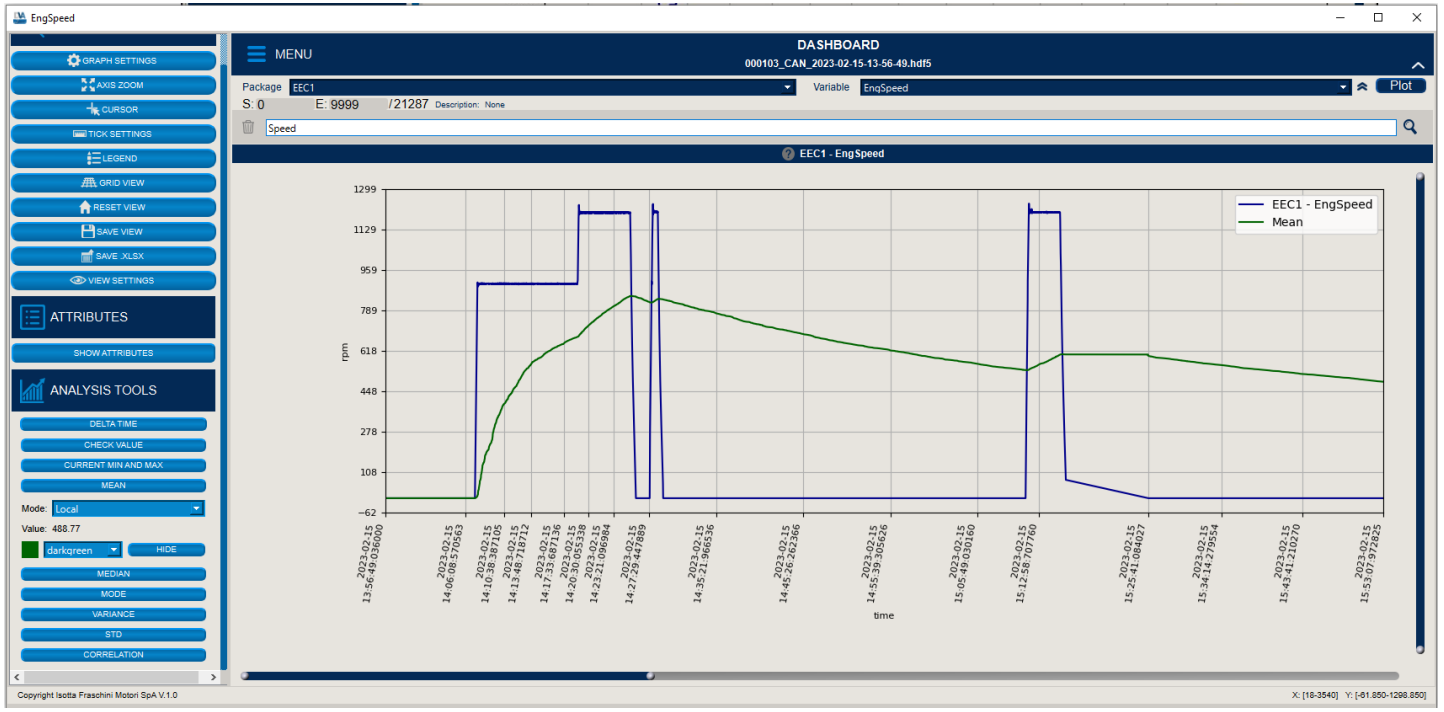
IFM has developed a diagnostic SW tool for Visualization and Analysis of data stored within HDF5 files.



- **A single-user file is required to start the SW tool. The user file is crypted and is filled with configuration secure information.**



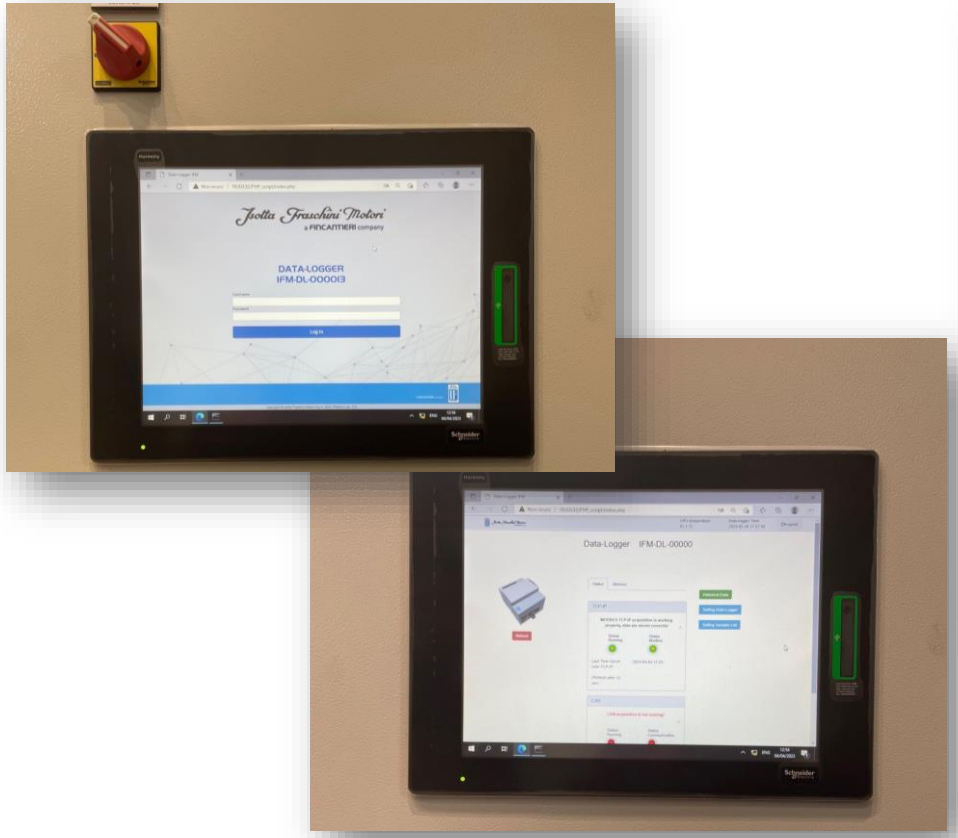
- **More than one file can be uploaded simultaneously.**
- **The SW tool can understand autonomously the communication protocol of the specific HDF5.**



- **More than one variable per single file can be uploaded simultaneously and compared with other variables of the same HDF5 file or another file.**
- **The SW tool upload all attributes to make easier the file reading.**

HDF5 VISUALIZATION TOOL *[IFM development]*

A real application of the SW tool based on HDF5 file usage is here reported:



Connection to the local device where HDF5 are stored by means of the HMI.

Running the SW tool for uploading the retrieved HDF5 files.

Start the Visualization and Analysis of the data.

CONCLUSIONS AND FUTURE WORK

- We have proposed an approach to **standardize** the storage of data acquired over simple or complex systems where single or multiple communication protocols are involved
- We believe that this approach can help to **democratize** the data usability among different vessel subsystem providers
- The approach could be extended to **other contexts** far from marine engines as automotive and micro-mobility.
- Main **HDF5 advantages**:
  - Capability to organize data in user-friendly architecture (path-to-resource)
  - Data storage optimization
  - Parallel IO
  - Capable to handle multi-dimensional arrays
- **Extended on-field tests** will be executed to evaluate the impact of HDF5 file format on large scale.

Thanks for your time