POLITECNICO DI TORINO

Master's Degree in Mechatronic Engineering

Analysis and optimisation of a pleasure boat's electrical system using home automation technologies and power monitoring: study applied to a 53-foot flybridge yacht

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A mamma e papà,
per aver sempre creduto in me,
per l'amore che mi dimostrate ogni giorno.

Abstract

The thesis focuses on the analysis and optimisation of the electrical system of a pleasure boat, to assess the possibility and feasibility of switching from an electromechanical to an electronic system, taking the automotive and home automation sectors as a reference.

The work was carried out at Electrical Marine, a company that designs electrical systems for boats.

The first project concerns the implementation of Schneider Electric's PowerTag, a power monitoring system for acquiring electrical parameters on AC utilities. In fact, considering that the goal of the nautical world is to move towards electric power, it is necessary to understand the effective consumption of loads in order to correctly size the capacity of lithium batteries.

ABB's Power Monitoring proposal (InSite) is also presented, which is capable of monitoring both direct and alternating current loads, but which has not been integrated due to time constraints.

The second project concerns the replacement of the current lighting panel, containing relays and fuses, with two home automation solutions, one wireless (EnOcean) and the other wired (KNX).

A technical and economic comparison between the two proposals is presented, through an analysis of costs, weights and compatibility with nautical standards.

The results show that, at almost the same cost as the current electromechanical implementation, bus communication and sensor integration can reduce weight and space and, above all, move towards an increasingly digital and intelligent direction.

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1.INTRODUCTION

This thesis presents the work carried out at Electrical Marine, a company that deals with the design and implementation of electrical systems for yachts.

The goal is to verify whether the electromechanical system of a boat can be converted into a more integrated network, considering the economic aspect, weights and installation times.

The nautical world is working to get closer to the automotive world, in which everything is now controlled by electronic control units connected to each other by CAN-bus technology; the goal is to get some benefit: improved performance reliability and cost saving.

Before the development of CAN-bus, around the 80s, every time an electronic feature was added inside a vehicle, additional cables had to be added and therefore over time with the arrival of new technologies, there was a significant increase in the number of cables.

With the introduction of CAN, the new electronic features and the switch that powers them can simply communicate through the existing network, which, however, requires additional programming to connect all devices.

A direct comparison cannot be made between a car and a boat for the following reasons:

- Different circuit composition;
- Different regulations in force;
- Different usage environment;
- Nautical sales numbers much lower than those of the automotive industry.

In particular, the following aspects are addressed in the development of the following projects:

- Power Monitoring;
- Replacement of the current light panel.

2. THE NAUTICAL INDUSTRY

2.1 DEFINITION AND CLASSIFICATION OF PLEASURE CRAFTS

From Article 3 of the Pleasure Boating Code, pleasure craft are *hulls of any material and any propulsion intended for sporting and recreational use*.

Until 2005, the classification of the pleasure craft was based on the type of propulsion, from that year onwards it is based on length, regardless of whether they are rowing, sailing, motor or pedal.

Therefore, according to Article 3 of the Recreational Boating Code, for the Legislative Decree of 18 July 2005, we mean *any vehicle intended for navigation for recreational or sporting purposes, not intended for commercial use*.

Article 3 shows the division of pleasure craft:

- **Watercraft**: In the Italian legal system, pleasure craft are defined *as boats whose hull, measured according to the harmonized standards EN/ISO/DIS 8666, has a length equal to or less than 10 m, regardless of their propulsion, with the exclusion of jet skis.*
  Boats, as a category of pleasure craft, exist only in Italian law and are excluded from the obligation to be registered in the registers of pleasure boats (R.I.D.) kept by the Port Authorities, the Maritime District Offices and the Civil Motorization Offices and therefore they are unregistered movable property. [1]

Figure 1: Watercraft

- **Boat**: *any unit with a hull length of more than ten meters and up to twenty-four meters, measured according to the harmonized standard UNI/EN/ISO/8666.* From Article 25: it displays the *national flag and is distinguished by an identification number consisting of an alphanumeric code, consisting of four alphabetic characters and four numeric characters in sequence. The identification number is followed by the letter "D" which indicates "pleasure boating". The code can also be decided by the owner as long as it is not already in use for the identification of another pleasure craft and that it is not contrary to public order, public morality and morality.* [1] [2]

Figure 2: Boat

- **Ship**: *unit over 24 meters*. As explained above for the boat, according to Article 25, *they will hoist a flag and the alphanumeric code will be followed by the initials ND*. It can be *greater if it has a tonnage greater than 600 gross tonnage or lower if the tonnage is up to 600 gross tonnages*.

  The ship is considered a *historic pleasure boat if its hull has a length of more than twenty-four meters, measured according to the harmonized standard UNI/EN/ISO/8666 and tonnage up to 100 GRT, built before January 1, 1967.* [1] [2]

Figure 3: Ship

- **Jet ski**: *any recreational craft with a hull length of less than four meters, which uses a propulsion engine with a water jet pump as its primary source of propulsion and intended to be operated by one or more persons sitting, standing or kneeling on the hull, rather than inside it.* [1]

Figure 4: jet ski

- **Remotely controlled pleasure craft**: *Remotely controlled pleasure craft without command personnel on board.* [1]

2.2 HISTORY OF THE ITALIAN NAUTICAL MARKET

The history of the Italian naval market began in the 1800s, initially focusing on the sector of sails with small and medium hulls for coastal navigation and offshore merchant sailing ships, robust and fast to face the open sea.

At this time, the reputation of a shipyard was decreed by the quality of the boat and the shipyards themselves took care of all the phases of construction, fitting out and finishing in-house. In 1875, Italy occupied fourth place in the world for the number of sailing ships engaged in long and medium routes.

In the early twentieth century, the crisis in the United States led to a downsizing of hulls in sport but, at the same time, the concept of powerboating was born due to the invention of the internal combustion engine and the cruising yacht began to distinguish itself from the racing yacht.

Powerboating developed a lot in Italy, France and the United States, with Italy excelling for great builders, designers and pilots. Thanks to the spread of small boats, boating began to extend to industrialized countries, no longer being exclusive to great navigators and noble families.

Shortly before the First World War, mass production had increased production potential and efficiency.

The '30s are considered as an age of research and continuous improvement of technological performance, in which a modern concept of yachts was born, i.e. large, luxurious and motor boats.

Historically, the Italian boating industry had focused on heavy construction (commercial, transport, fishing), but between the two wars there was an attempt to bring Italians closer to the sea by promoting nautical tourism, laying the foundations for boating as an industry.

Clearly, the concept of owner and boat also changed, moving from nobles with large boats to a wider market with a larger number of customers and smaller boats.

In 1928 the first 'Powerboat Show' was held at the Milan fair. During the Second World War, the largest shipyards continued to build merchant sailing ships, but the market temporarily turned to military vessels that guaranteed stability of orders.

After the war, many construction sites were destroyed, but they recovered thanks to the contributions of entrepreneurial families and workers. The experience gained in military construction was applied to the world of yachts, bringing great technical improvements.

Italian shipyards were among the first to enter the market of comfortable and elegant motorboats, combining luxury and prestige. With the economic reconstruction, the market for motor and sailing pleasure boating developed for the bourgeois class, with a majority of boats built in wood.

The shipyards were mainly located on the lakes of Northern Italy or in coastal areas with a maritime tradition.

In the fifties, the boating industry adopted mass production, guaranteeing stock production but also preserving craftsmanship.

At the same time, large prototypes began to be built to order, giving way to the customization of the boat and it is precisely from here that the concept of the large personal motor boat was born. Commercial ships were also transformed into pleasure boats to meet the new market and the first foreign orders began to arrive, laying the foundations for the future leadership of the Italian naval sector.

In 1962, the Genoa Boat Show opened for the first time.

Technical innovations such as marine plywood and superlamellar were introduced, which allowed new construction techniques such as interior prefabrication.

But the greatest innovation was the transition to fiberglass, which expanded the spread of boats and changed the design philosophy. Fiberglass offers several advantages, including light weight, chemical and corrosion resistance, and long service life.

In the 80s, the nautical market expanded further, receiving orders from other continents and structuring itself for mass production. The size of the boats grew, allowing designers to express themselves at their best and owners to have more space.

In the nineties, there was the international consolidation of the main Italian shipyards, with flocks to the American markets. In 1993 another crisis led to a 30% drop in sales due to increased taxation on boats, but the impact was limited because in the following decades the growth was exponential.

The quality of the boat improved and the Italian yacht became a symbol of planning, traditional craftsmanship and distinctive design and to stimulate demand, the life cycles of the models were shortened (5 years on average). During this period, the *Azimut-Benetti* shipyard became Europe's leading manufacturer of motorboats and became the world's leading manufacturer of megayachts. Sailboats also grew in size, requiring more comfort and speed.

In the 2000s, with the increase in production capacity, construction sites began to be built closer to the sea and an additional entrepreneurial challenge was the creation of real tourist centers in ports, not just landing areas.

Azimut-Benetti was awarded as the first megayacht manufacturer for 12 consecutive years.

With the 2008 crisis, there was a drop in sales and a reduction in production in many plants, then recovering in 2015 with an increase in orders and an improvement in the entire field

The sector is growing steadily even after the pandemic crisis, thanks to operational improvements and effective production management.

Currently, demand exceeds supply with a growth in demand for customization and tailor-made solutions and Italy confirms itself as the global leader in the production of super yachts thanks to shipyards such as: Azimut-Benetti, Ferretti Group and Sanlorenzo. [3]

3. THE BOAT

3.1 BOAT STRUCTURE

The boat used as benchmark, Azimut 53F, in which the 'F' indicates the presence of the Flybridge, has an overall length of 16.78 meters, with four cabins including a crew cabin.

Figure 5: Azimuth 53F

Its structure is divided into:

- Main deck: containing both the interior spaces, such as the galley, lounge and wheelhouse station, and the outdoor spaces aft and bow.

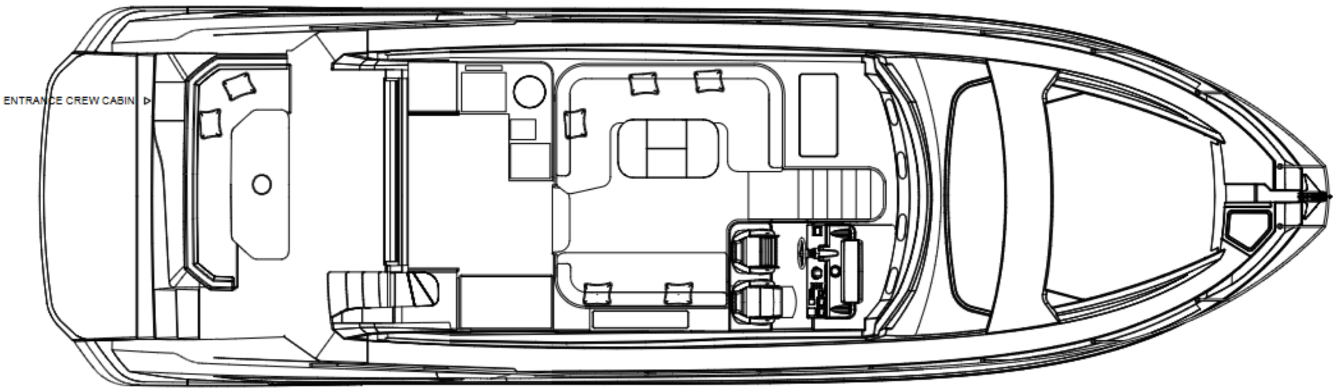


Figure 6: main deck

- Lower deck: below the main deck, containing the crew cabin, the owner cabin, the guest cabin and the VIP cabin, with their respective bathrooms.

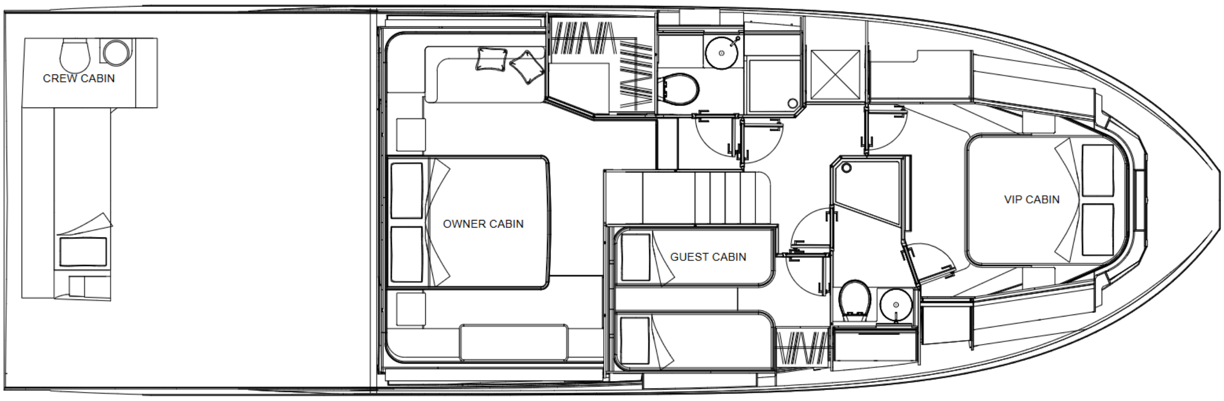


Figure 7: Lower Deck

- Sundeck: above the main deck, containing another wheelhouse station

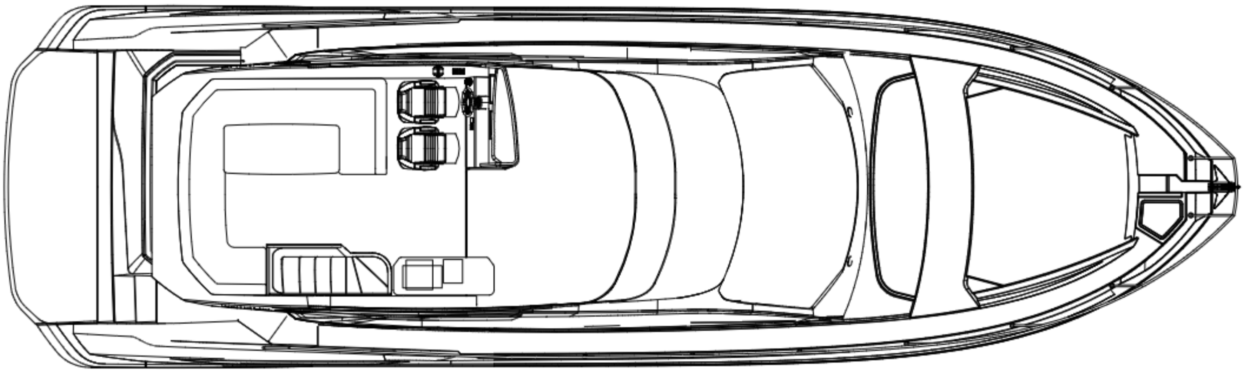


Figure 8: Sundeck

Figure 9: Sundeck

3.2 DESCRIPTION OF THE ELECTRICAL SYSTEM

The electrical system of a boat is the whole of electrical installations and components intended for the generation, conversion and distribution of electricity.

It can be divided into charging and distribution.

The first part supplies energy to the batteries, the second distributes electricity to the various on-board users.

The electricity inside the boat can come from shore outlets (port docks), batteries, or power generators.

It is important to note that both direct current (12 V or 24 V) is used on the boat for services, for starting the main engines and generators, and 220 V alternating current for other utilities.

3.3 ELEMENTS PLACEMENT

The Lower Deck is organized as follows:

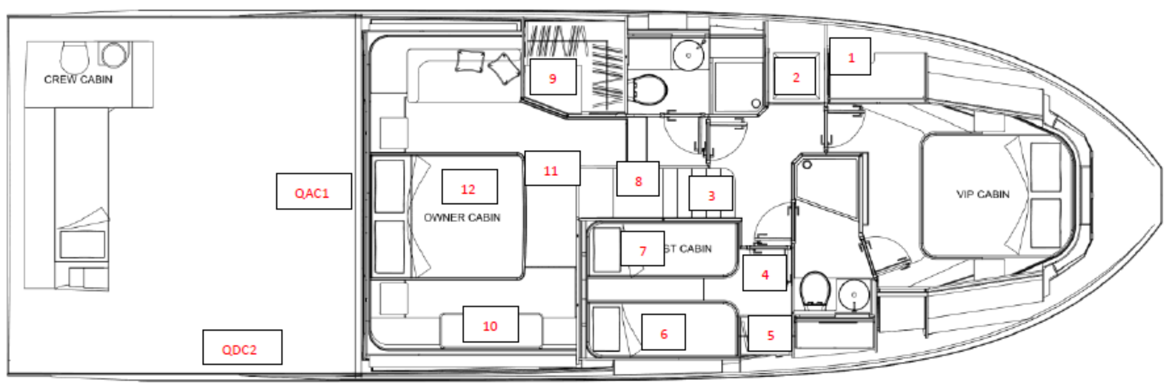


Figure 10:lower deck organization

1. VIP CABIN: Lighting Panel and A/C Control Unit
2. CORRIDOR: A/C wheelhouse and washer-dryer socket
3. CORRIDOR: Volvo-Reactor 40 Autopilot
4. GUEST CABIN: A/C condensate pump
5. GUEST CABIN: Guest A/C control unit and WC control unit
6. GUEST CABIN: QDC4 positioned at the top left

7. GUEST CABIN: 220V utility box and Service Batteries
8. HALLWAY: QDC1
9. OWNER'S CABIN: Slave A/C control unit and WC control unit
10. OWNER'S CABIN: Master A/C control unit
11. OWNER's CABIN: Transducer + Fish Finder (OPT)
12. OWNER'S CABIN: Air conditioning condensate pump

The organization of the Main Deck includes:

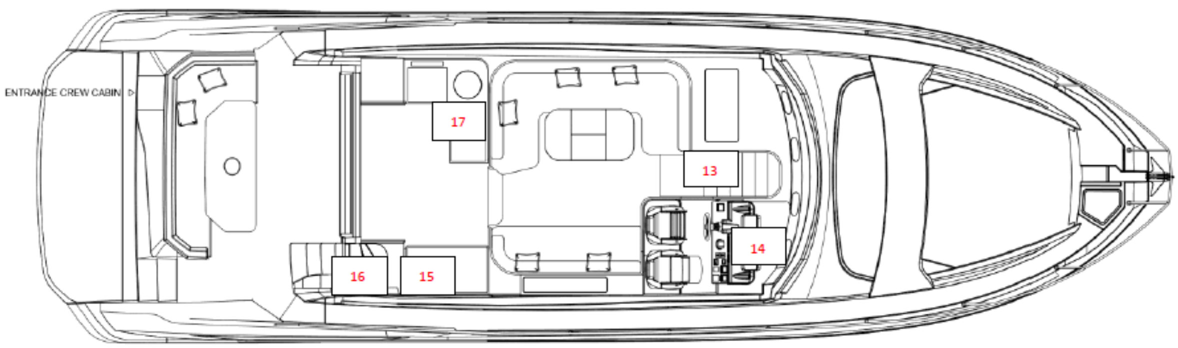


Figure 11: main deck organization

13. CORRIDOR: Owner's cabin audio/video box
14. Main Deck Dashboard
15. 24V and 220V panels
16. A/C master-slave control units for the living room/kitchen
17. Saloon/kitchen slave A/C control unit

On the Sun Deck:

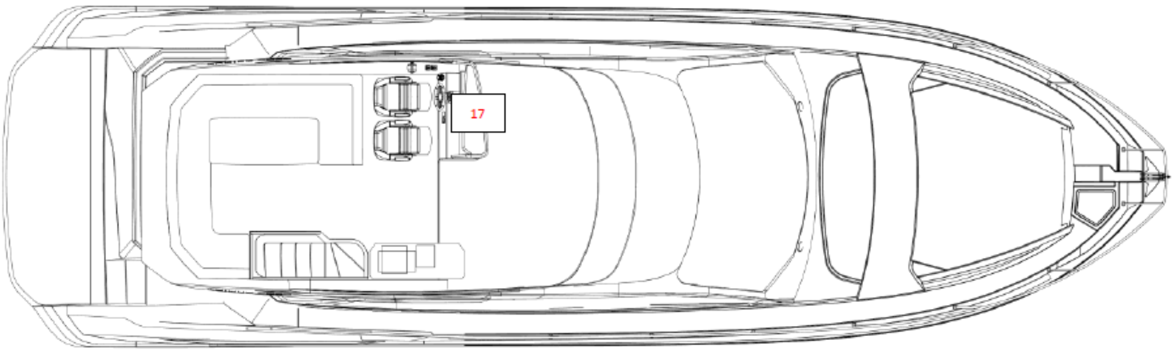


Figure 12: Sun deck organization

18. Fly dashboard

3.4 ENERGY SOURCES

As explained above, the electricity on board can come from three sources.

3.4.1 GENERATORS

The power generator makes the yacht independent of shore power, ensuring the presence of alternating current even while underway.

For the European version, the single-phase generator used is powered by diesel at 3000 rpm, capable of delivering a power of 5 kW (230 V at 50 Hz).

The generator is connected to the main electrical panel in alternating current in the engine room, has its own starter battery and its own battery switch. The starter battery is of the AGM type, with a high instantaneous discharge capacity and a capacity of 70 Ah at 12 Vdc.

It is protected by a differential circuit breaker, installed within 3 meters of the generator itself, with a maximum nominal trip sensitivity of 30 mA and a maximum tripping time of 100 ms.

3.4.2 THE GROUND SOCKETS

In the standard configuration there is a single-phase 230 Vac 50 A shore socket on the transom and connected to the on-board system.

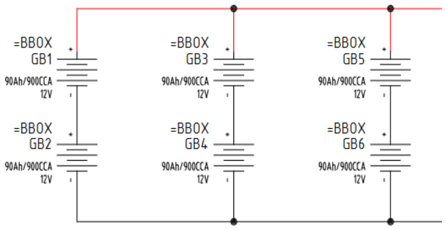
3.4.3 BATTERY SYSTEM AND CHARGING

The batteries are all of the AGM type, an acronym for Absorbed Glass Mat, which have an absorbent microfiber glass felt inside for the liquid acid.

This traps battery acid in such a way that it makes better use of the battery's tight space and volume – better performance for the same size.

Thanks to their compactness, they have a better resistance to vibrations than standard batteries and thanks to the type of construction that does not allow them to be opened, they are maintenance-free.

- *SERVICE BATTERIES:*



Total capacity battery bank: 90Ah × 3=270 Ah@24V

In the engine room there is a 60 A / 24 Vdc automatic charger, but in addition to this, the batteries will also be charged by the alternator of the left engine.

Clearly this battery bank has its own battery switch in the Lower Deck corridor area and the charging and discharging current of the batteries is monitored by current probes with RS485 interface, connected with the monitoring system.

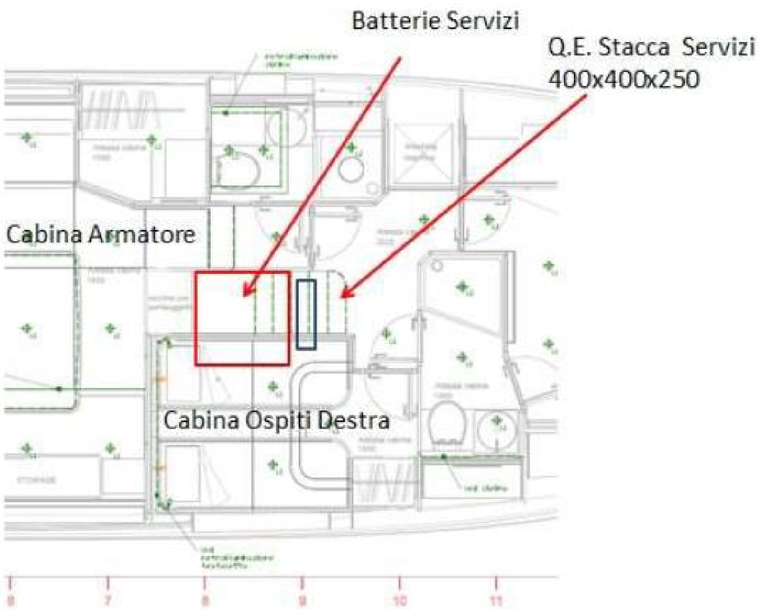


Figure 13:service batteries and battery switch

- *ENGINE STARTER BATTERIES:*

  There are two main engine starter battery banks (right and left), each of which contains two 12V elements, connected to a capacity of 90 Ah@24V.

  These batteries are also of the AGM type, a 60A/24Vdc automatic service charger output is connected directly to the batteries of the left motor, another output of the charger is connected to the batteries of the right engine via transfer case. The batteries of the right and left engines are also charged via the engine alternator via the transfer case.

  There is a battery switch for each starter battery pack and the engine battery voltage is detected through the monitoring system.

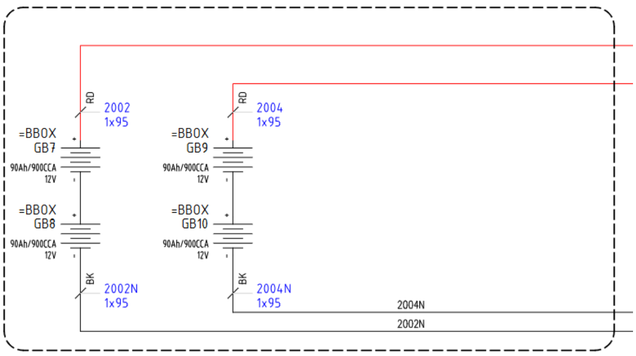


Figure 14: battery pack electrical circuit

- *GENERATOR STARTER BATTERIES:*

  The starter battery bank has a capacity of 70 Ah@12V, consists of a 12 V element, always talking about AGM type batteries.

  The battery charger is powered by the main panel at 230 V, 10A/12Vdc.

  Also in this case, the voltage of each starter battery is detected by means of transducers connected to the electronic control unit and subsequently reported.

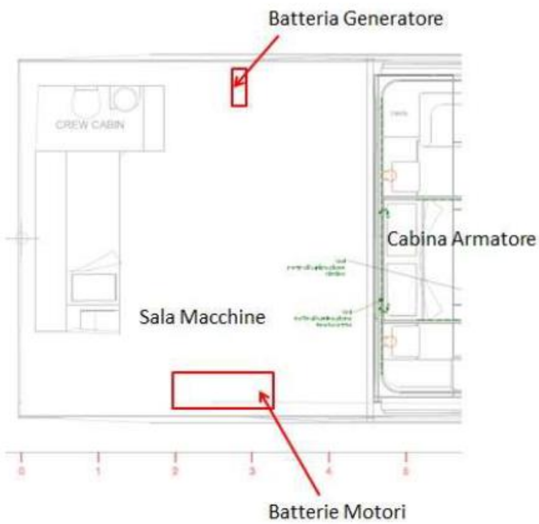


Figure 15: motor batteries and generator battery

Even in the automotive field, the type of battery used is AGM, what changes from the circuit of the boat is clearly the number. In fact, in the conventional car there is only the starter battery which has the task of powering the engine starter, lights and other electronic devices.

3.4.4 BATTERY SYSTEM AND CHARGING EXAMPLE DIAGRAM

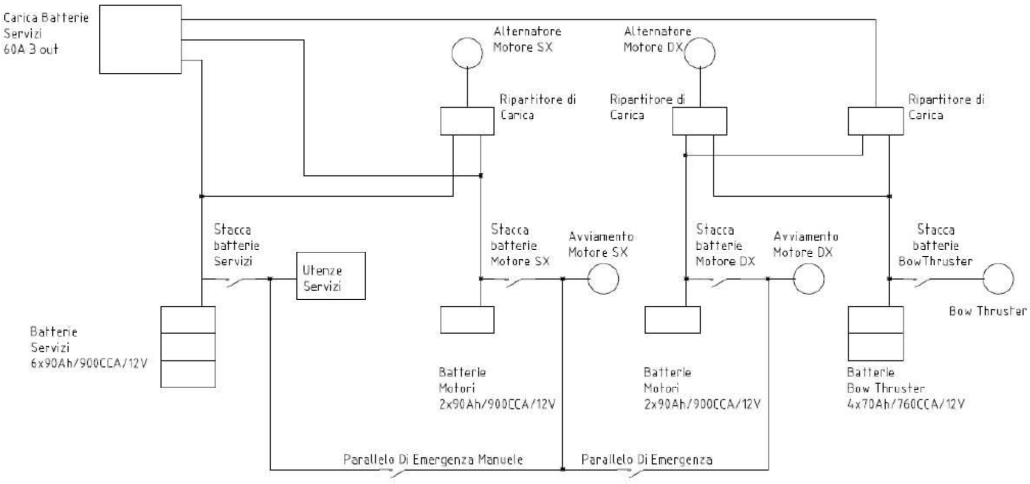


Figure 16: battery and charging system diagram

Charging systems:

- Charger: one charger for the 60A@24Vcc service battery bank and one for the 12A@12Vcc generator battery bank;
- Alternators: through the transfer cases, the left engine alternator charges the service battery bank and the left engine battery bank, while the right engine alternator charges the right engine battery bank and the bow thruster battery bank.

There are:

- a temporary and adequately marked parallel of the engine starting benches;
- a manual emergency parallel between the motor and service batteries.

They allow one engine to be started using the energy of the other, in the event of a failure or a dead battery.

Each battery has its own battery switch, which is essential for the safety and protection of the batteries and the system. In particular, through the battery switch the following advantages are present: [14]

- Battery insulation: by nature, batteries on board tend to discharge even when the boat is not in use due to current leakage; So, this conserves battery power, completely cutting off the flow of current between the battery and the electrical system when the boat is not in use, preventing the risk of discharging it completely.
- Safety and protection against short circuits: In the event of a short circuit or overload of the system, it interrupts the flow of current, reducing the damage that could occur.
- Targeted power distribution: Enables targeted power distribution when the alternator or charger is in operation.

Clearly, the battery switch is not widespread in the car for several reasons:

- The car does not act in a saline and humid environment like the one in which the boat works, therefore having less current leakage;
- The average use of a car is greater than that of a boat, which over the course of a year, can be defined as occasional;
- The boat has a very high number of power users, considering all the services and lights; So, the battery disconnect eliminates the hassle of forgetting something on.

3.4.5 POWER AVAILABILITY: BOAT VS CAR

	BOAT (53F)	**CAR (any car)**
Installed power DC (Ah)	520	70
Installed power AC (kW)	5-15	none

Table 1: comparison between power availability of the boat and the car

3.5 PROTECTIVE EQUIPMENT

3.5.1 CIRCUIT BREAKER

It is a safety device that intervenes by interrupting the flow of electric current in the event of an overload (thermal protection) or short circuit (magnetic protection).

Figure 17: circuit breaker

In the event of a short circuit, the current can be so high that it can damage the electrical system and put the safety of the people on board at risk. The voice magnetothermic coil, which detects the short circuit, is a solenoid wound on a bar of ferromagnetic material, and the magnetic force, generated by the high short-circuit current, overcomes the resistance of the spring by tripping the magnetic release of the switch and opening the circuit.

In the event of an overload, the heat produced by the passing current is monitored by the circuit breaker that opens the circuit, isolating the system, when it detects a temperature that exceeds a certain threshold. Detection is done through a bimetallic foil that acts as an electrical resistance if overheated by the high temperatures of the overload. Due to the different coefficient of thermal expansion of the two metals that make up the foil, the latter stretch differently when overheated, causing the switch to trip and the circuit to open.

Tripping is not immediate, and the tripping curve determines how long a certain overload current can be tolerated.

In general, the higher the overload current, the shorter the tripping time of the protection. [4]

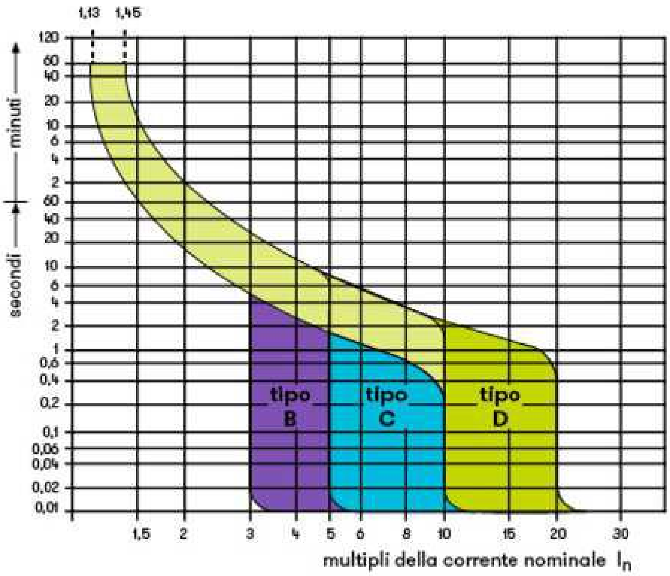


Figure 18: Tripping curve

3.5.2 DIFFERENTIAL SWITCH

It is a safety device capable of interrupting the electrical flow in a circuit in the event of electrical leakage or phase-to-earth electrocution, by detecting the current difference between input and output; It does not offer protection against overload or short-circuit between phase to phase or between phase and neutral.

Normally, the current flowing in the phase conductor (current to load) is equal to the current flowing back through the neutral (current from the load). The currents, therefore, cancel each other out in the torus and do not generate a magnetic field, leaving the switch closed and allowing the current to pass through.

If there is a significant difference between the two currents, there is a dangerous leakage to ground, so the current returning through the neutral will be less than that flowing in the phase, generating a magnetic field that induces a current in the coil. This induced current activates the electromagnetic relay that operates the opening of the contacts, preventing current leakage. [4][5]

Figure 19: residual current circuit breaker

3.5.3 DIFFERENTIAL CIRCUIT BREAKER

It combines the circuit breaker, to protect against short circuits and overloads, and the differential switch, which intervenes in the event of current leakage, in order to reduce the risk of electric shock and make the system safer.

The protection against short circuits and overloads takes place exactly as it was described above for the circuit breaker, the residual current protection has the function of controlling the electrical current entering and leaving the system. The input value must be equal to the output value; therefore, if the two parameters do not match, it means that the current is being dispersed and the circuit is opened with a time proportional to the value of the differential current. [6]

Figure 20: residual current circuit breaker

3.5.4 FUSE

It is an electrical device that can protect a circuit from overloads and short circuits. It consists of a cartridge, crossed by a conducting wire through which the nominal current of the circuit passes. When an overcurrent arrives, the filament melts, causing the circuit to open.

Figure 21:fuse

3.5.5 CIRCUIT PROTECTIONS: BOAT VS CAR

Clearly, on a car there is no differential switch, as there is no AC current.

Regarding the DC protection, there are some fuses, that now come in the form of Electronic Fuses (eFuses).

They are integrated circuits that can replace larger conventional fuses or other protection devices such as resettable polymeric fuses.

They are contained in small plastic packages, they integrate a control circuit and a power switch with low on-resistance, connecting the input port to the load.

The advantages of the eFuse are the higher speed of intervention and the ability of not to be replaced after actuation.

3.6 DISTRIBUTION SYSTEM

It is the set of equipment, panels, components suitably connected to each other to sort the energy received from the connections to the main and emergency electrical panels to which the generators are attached. [7]

It is radial and is divided into primary and secondary distribution systems, each of which includes:

- Processing equipment;
- Power lines-cables;
- Protective equipment;
- Switchboards, distribution boards and switchboards in which an identification plate will be affixed that will contain the following information:
  - Identification;
  - Destination vessel;
  - Date of construction/testing;
  - Manufacturer;
  - Weight.

3.6.1 DC DISTRIBUTION SYSTEM

Figure 22: continuous distribution system

The direct current distribution system is made as follows:

- 24 V direct current system for services/emergencies: distribution system with negative ground.
- 24 V direct current system for starting main engines: distribution system with negative in common between the two batteries and grounded in a single point.
- 12 V direct current system for starting generators: system with negative in common between the two batteries and grounded in a single point.

The electrical panels are divided as follows:

- **QDC1:** receives energy directly from the service battery bank, so this implies the presence of the QSV service battery switch. On the same 2001 line, there is the bilge pump protected by a 32A fuse.

  From the 2016 line of the service battery switch, the 2016 line begins, from which line-1 QDC3 and line-2 QDC3 depart, both protected by two 80A fuses.

- **QDC2:** on the 2001 line there is the gangway control unit, protected by a 50A fuse.

  Since 2016, the following services have been branched:
    - QDC2 Line-1: Protected by an 80A fuse;
    - Platform: protected by a 100A fuse;
    - STBD winch: protected by a 60A circuit breaker;
    - Port winch: protected by a 60A circuit breaker;
    - Windlass: protected by an 80A circuit breaker;
    - Fly bimini: protected by an 80A circuit breaker;
    - Hard top curtain: protected by a 10A circuit breaker;
    - QDC2 Line-2: Protected by an 80A fuse.

  From line-1 QDC2, cable 2037 starts, on which the following lines are available:
    - Transfer pump: 10 A magnetothermic protection;
    - Engine room lights: protected by 6 A circuit breaker;
    - Monitoring: protected by 20 A circuit breaker;
    - Spare: protected by 16 A circuit breaker;
    - Spare: protected by 16 A circuit breaker;
    - Spare: protected by 10 A circuit breaker;

- Curtain inverter: protected by 16 A circuit breaker;

From the QDC2 line-2, the 2038 cable starts, on which there are the following lines:

- Engine room extractors: protected by 20 A circuit breaker;
- Crew cabin WC: protected by 32 A circuit breaker;
- Cable reel control unit: protected by 10 A circuit breaker;
- Flybridge table: protected by 10 A circuit breaker;
- AIS: protected by 10 A circuit breaker;
- Gyro DC stabilizer: protected by 10 A circuit breaker;
- DC Pump Stabilizer: protected by 10 A circuit breaker;
- Chlorinator: protected by 16 A circuit breaker.

- **QDC3:**

From line-1-QDC3, line 2035 starts, on which there are:

- Trim tabs: protected by 15 A circuit breaker;
- Navigation instruments: protected by 20 A circuit breaker;
- Dashboard: protected by 10 A circuit breaker;
- Emergency panel: protected by 5 A circuit breaker;
- Wipers: protected by 20 A circuit breaker;
- Horn: protected by 20 A circuit breaker;
- Fresh water pump: protected by 30 A circuit breaker;
- Grey water pump: protected by a 10 A circuit breaker;
- Black water pump: protected by a 10 A circuit breaker;
- Fly fridge: protected by a 10 A circuit breaker;
- HiFi: protected by 10 A circuit breaker;

- Helm seat: protected by 10 A circuit breaker;
- Aux: protected by 10 A circuit breaker;

From line-2-QDC3, line 2036 starts, on which you have:

- Guest cabin WC: protected by 30 A circuit breaker;
- Owner's cabin WC: protected by a 30 A circuit breaker;
- Cockpit fridge: protected by a 15 A circuit breaker;
- Winecooler: protected by a 10 A circuit breaker;
- Spare: protected by 10 A circuit breaker;
- Cabin lights: protected by 15 A circuit breaker;
- Saloon/galley lights: protected by 15 A circuit breaker;
- Cockpit lights: protected by 10 A circuit breaker;
- Step lights: protected by 10 A circuit breaker;
- Galley fridge: protected by 10 A circuit breaker;
- VHF/Radio: protected by 10 A circuit breaker;
- 12V sockets: protected by 15 A circuit breaker;
- Searchlight: protected by 20 A circuit breaker;
- Optional lights: protected by 10 A circuit breaker.

3.6.2 AC DISTRIBUTION SYSTEM

Figure 23: alternating distribution system

In **QAC1:**

- Shore 1, powered by a Shore-1 230V (AC) shore socket at 50 Hz, through the general Dock-1, protected by a 50 A circuit breaker;
- Generator 1, powered by the 50 Hz alternating current generator, through the general generator, protected by a magnetothermic;
- Shore 2, powered by a Shore-2 230V (AC) shore socket at 50 Hz, through the general Shore-2, protected by a 50 A circuit breaker;

These two bars of the 230 V system are divided into two sections that each supply half of the on-board loads. The two bar systems are divided by a switch:

- If closed: the generator or one of the two shore sockets powers the entire system;
- If open: The two shore outlets or one shore outlet and the generator power each half of the system.

From shore 1, there is the cable 8000, from which:

- Line-1 engine room/salon utilities: protected by a 100 A differential;
- A/C compressor: protected by a 32 A differential circuit breaker.

From shore 2, there is cable 8002, from which:

- Line-2 machine room/salon utilities: protected by a 100 A differential;
- Stabilizer: protected by a 20 A differential circuit breaker;
- Washing machine: protected by a 16 A differential circuit breaker.

From Line-1 engine room/salon utilities, line 8000/1:

- Line-1 salon utilities: protected by a 50 A circuit breaker;
- Crew cabin A/C fan coil: protected by a 6 A circuit breaker;
- Vacuum cleaner: protected by a 16 A circuit breaker.

From Line-2 engine room/salon users, we have line 8002/1:

- Line-2 salon users: protected by a 50 A circuit breaker;
- Engine room socket: protected by a 16 A circuit breaker;
- Crew socket: protected by a 16 A circuit breaker.

In **QAC3:**

From line-1 Salone users, you have line 8036:

- Main deck fan coils: protected by 6 A circuit breaker;
- Main cabins fan coils: protected by 6 A circuit breaker;
- Services Battery Charger: protected by a 15 A circuit breaker;

- GenSet Battery Charger: protected by 6 A circuit breaker;
- Water Heater: protected by a 15 A circuit breaker;
- Winecooler: protected by 10 A circuit breaker;
- Water maker: protected by 10 A circuit breaker;

From the saloon 2-user line, line 8038:

- Barbecue: protected by 20 A circuit breaker;
- Hi-Fi: protected by 15 A circuit breaker;
- Cockpit Icemaker: protected by 6 A circuit breaker;
- Oven: protected by 20 A circuit breaker;
- Range: protected by 30 A circuit breaker;
- Galley exhaust: protected by a 6 A circuit breaker;
- Fridge: protected by 10 A circuit breaker;
- DishWasher: protected by 10 A circuit breaker;
- Cabin Sockets: protected by 15 A circuit breaker;
- Saloon Sockets: protected by 15 A circuit breaker;
- Galley sockets: protected by 15 A circuit breaker;
- Winecooler: protected by a 10 A circuit breaker.

4. AUTOMOTIVE ELECTRICAL SYSTEM

Over the years, the number of electronic components inside motor vehicles has increased rapidly, as electronics improve vehicle handling, safety, and reduce environmental impact.
To date, the electronics include sensors, actuators, microprocessors, controllers and displays, which contribute to electronic stability control, tire pressure monitoring, lane departure warning, forward collision warning and automatic braking.
The electronics have also been able to improve the operation of engines and other propulsion systems, heating and cooling systems, decreasing fuel consumption and harmful emissions, improving environmental impact.
Another key aspect is the reduction in vehicle weight, as the electronic components are significantly lighter than the mechanical ones, leading to better energy efficiency.
The electrical system of a machine includes: current sources, current consumers, control elements and electrical cables.

4.1 CURRENT SOURCES

The current sources are the generator and the battery.

4.1.1 GENERATOR

It converts mechanical energy into electrical energy to power the car's electrical equipment and to charge the battery. There are two types of generator: alternator or direct current generator.
The alternator is most prevalent in cars and is a twelve-pole three-phase synchronous electric machine with a block of semiconductor rectifiers, silicon diodes that convert alternating current into constant current. The generator rotor is driven by a crankshaft pulley via a belt drive.

4.1.2 BATTERY

It is used to power the control circuits and the on-board electrical system when the engine is not running, but its main purpose is to start the engine.

4.2 POWER CONSUMERS

These are the devices that harness energy to ensure the operation of the vehicle.

4.2.1 IGNITION CIRCUIT

The ignition circuit sends sparks to the engine to make it work properly. A distributor times when sparks should occur. In the distributor cap, a rotor touches each spark plug wire, sending a spark to each spark plug one after the other. The spark plugs are in the engine and create sparks when electricity jumps through a slot in the plug.

4.2.2 STARTING CIRCUIT

The starting circuit helps to start the engine using electricity when you turn the car key to start, a small current goes to the starter solenoid which protects the small wires from the large power required for the starter. The solenoid lets electricity flow to the starter motor, so it helps start the engine until it runs on its own.

4.2.3 LIGHTING AND SIGNALING SYSTEM

It consumes electricity and ensures the operation of the lights, turn signals, fog lights and position lights. Control and measurement instruments ensure that operating parameters are controlled and allow the driver to monitor them.

4.3 ELECTRONIC CONTROL UNITS

The electronic control unit (ECU) is defined as the brain of the car, managing the various systems by processing data from sensors and sending commands to actuators, in real time.

The ECU controls functions such as engine management, braking systems, and transmission, ensuring the effectiveness of the vehicle. In modern cars, there are multiple ECUs, each responsible for a different function.

Sensors in the vehicle measure parameters such as engine temperature, speed and air pressure; this data is sent as input to the ECU microcontroller which analyzes it using pre-programmed algorithms and calibration tables.

Based on the analysis, the ECU determines the action needed and sends the signals to the actuators to implement the responses.

An electronic control unit consists of:

- Microcontroller: executes instructions and processes data;
- Memory: ROM, RAM, and flash memory to store software, calibration data, and temporary information during operation;
- Input/output interface: connection between the ECU, sensors (input) and actuators (output);
- Power Circuit: Provides stable power to components;
- Communication BUS: allows the ECUs to communicate with each other, via CAN, LIN or FlexRay technologies;
- Enclosure: Protects internal components from heat, moisture and vibration.

The main functions are:

- Engine Control: Manages fuel injection, ignition time, and air-fuel mixture to improve engine performance;
- Transmission Control: Controls gear changes and torque converter operations;
- Brake system: Adjusts the anti-lock braking system and electronic stability control;
- Infotainment: controls audio, navigation and user interface systems;
- ADAS: lane keeping assist, adaptive cruise control and collision warning.

In cars, the different control units present communicate with each other via CAN Bus technology, an acronym for Controller Area Network. It is a communication protocol created in the 80s by Bosch and allows electronic devices to exchange data in real time on a physical bus, to which everyone is connected.

Communication is differential, i.e. data is transmitted as a voltage difference between two lines (CAN-High and CAN-low) and this makes it resistant to electrical interference. [9][10]

5. WIRING

5.1 THE WIRING IN THE CAR

The wiring harness is what connects every electrical component, from the headlights to the infotainment system, ensuring functionality in harmony. It represents the third heaviest and most expensive component of a car (after the body and engine): the thickest cable bundles are responsible for an increase in the weight of the car from 45 to 65 pounds (20-30 kilos), reaching a total wiring weight of 50-55 kilos.

In older cars, each function was managed by an ECU separate from the others and connected by a sprawling network of cables, which led to an extension of the wiring up to 5000 meters, thus not guaranteeing lightness and total efficiency.

To try to reduce the heaviness of the car, car manufacturers have integrated multiple functions into a single controller, for example, all those related to driving such as steering and braking, are managed by a single controller. In this way, not only has the number of ECUs decreased, but the wiring has been reduced to about 2000 meters. It must be taken into account the fact that technologies such as Ethernet have improved the speed of communication, making the car smarter and more efficient.

The latest trend is centralized architecture, i.e. a single computer handles most of the car's processing, eliminating many ECUs and reducing the length of the wiring to 1500 meters, as can be seen in Tesla's Model 3. [11]

Having shorter wiring leads to numerous advantages:

- Cost savings: Less wiring also means fewer materials and easier assembly, leading to 30-40% savings in wiring costs and reduced production time.

- Weight reduction: considering that wiring harnesses represent 3-5% of the weight of a car, the latter can lose 10-20 kilograms, improving energy efficiency;
- Better performance: Shorter wiring leads to faster signal transmission, improving signal responsiveness, which in the case of autonomous driving systems can mean the difference between a safe stop and a collision.

5.2 CABLE PERFORMANCE CLASSES [12]

The performance classes of the cables are:

- Reaction to fire: they vary as a function of decreasing performance, from A_{ca} to F_{ca};

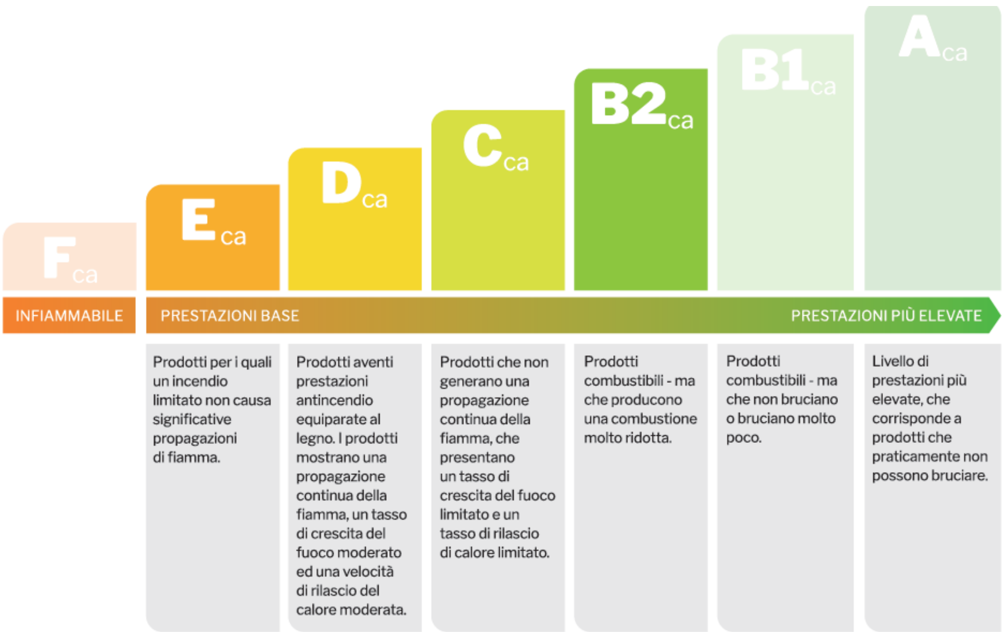


Figure 24: reaction to fire

- Smoke opacity (only for cables with classes B_{ca} to D_{ca} : varies from s1 to s3 with decreasing performance, s1a or s1b indicate a visibility greater than 80% or 60% respectively.

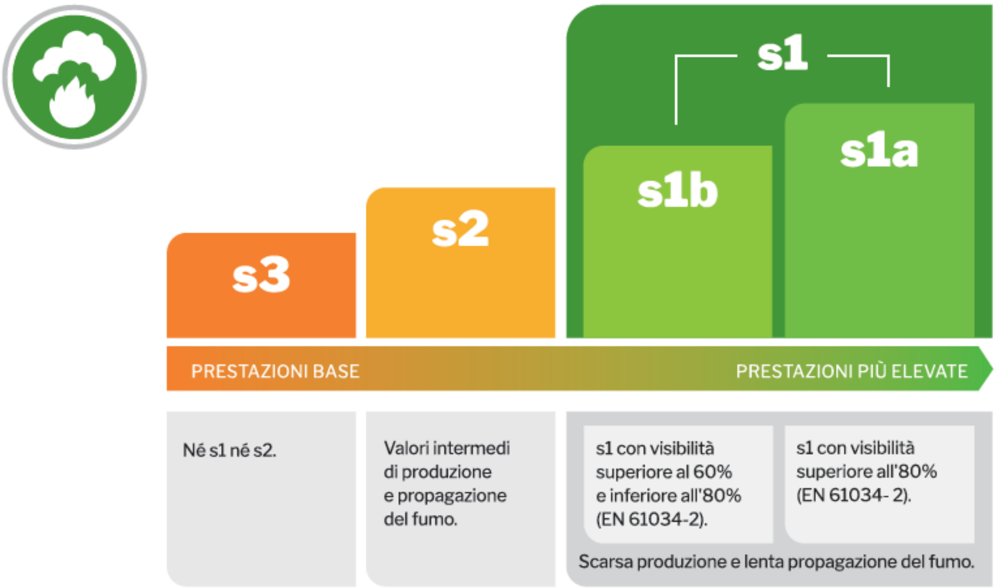


Figure 25: smoke opacity

- Glow particle dripping: ranges from d0 (no dripping) to d2 (continuous dripping) with decreasing performance.

Figure 26: Drip of independent particles

- Acidity: varies from a1 to a3 with decreasing performance and is attributed to cables with low fire risk, i.e. cables with low flame spread and heat release (classes B2ca and C_{ca}), low smoke hazard (class s1 and above) and low emissions (a1).

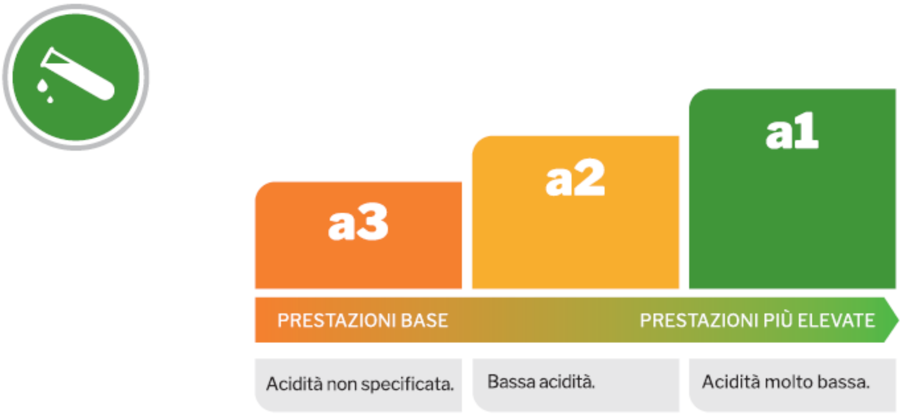


Figure 27:acidity

5.3 THE WIRING IN THE BOAT

To analyze the weights and measurements of the Azimut 53F's wiring, calculations were made based on the length and type of cables present in each section of the boat.

The length of the wiring harness is 4.832 km, a much higher value than the current 1.5 km of the car.

There is also a big difference in terms of weight: it has been estimated that it weighs about 630 kg, compared to 50 kg for the car. This enormous difference is due, of course, to the presence of electronic control units, computerized systems and CAN-bus technology that allows the car to drastically reduce the weight and lengths of the wiring. The same cannot be said when it comes to boats, both because currently the circuit is electromechanical, and because the size and number of services offered by a boat cannot be compared to those of a car.

5.3.1 CALCULATING WIRING WEIGHTS

In the table below, in the first column there is the formation of the cable (n° x mm2), while in the second the total meters of this cable present in the entire boat.

The estimate of the wiring weights was made by taking into consideration the types of cables present, as the technical data sheet of each type shows:

- Number of conductors: 1x,2x,3x, etc...;
- Nominal cross-section (mm^2);
- Conductor indicative diameter (mm);
- Average insulation thickness (mm);
- Maximum external diameter (mm);

- Approximate weight of the cable in kg/km;
- Electrical resistance at 20°C (Ohm/km);
- Current flow rate in air at 30°C (A);

In particular, taking into consideration the technical data sheets of two suppliers (General Cavi and Baldassari):

- FS17 450/750V, CPR Cca-s3, d1, a3: class 5 annealed red copper flexible conductor, S17 type PVC insulation. Of this type are 1.5 cables (white, blue, grey, brown, black, red and green) with a weight of 20 kg/km, 10 cables (brown, black and red) with a weight of 111 kg/km, 16 cables (blue, G/V, brown, black, red) with a weight of 163 kg/km, 2.5 cables (blue, G/V, grey, brown, black, red) with a weight of 31 kg/km, 25 cables (G/V, black, red) with a weight of 247 kg/km, 35 cables (G/V, black, red) with a weight of 336 kg/km, 4 cables (black, red) with a weight of 46 kg/km, 50 (black, red) red) with a weight of 483 kg/km, the 6 (black, red) with a weight of 64 kg/km, the 70 (black, red, G/V) with 64 kg/km and the cables 95 with a weight of 886 kg/km.
- FROR16 O.R., Cca-s2, d0, a3: class 5 red copper flexible conductor, PVC-based insulation, R2 quality. The stranding includes twisted cores with concentric crowns. The outer sheath is a PVC-based compound, R16 quality, resistant to oils. Cables belong to this category: 12x0.50 with a weight of 125 kg/km, 3x0.50 with a weight of 37 kg/km, 2x0.50 with a weight of 31 kg/km, 8x0.50 with a weight of 86 kg/km, 7x1.5 with 180 kg/km.
- FG16OR16, Cca-s3, d1, a3: class 5 annealed red copper flexible conductor, high modulus ethyl propylene rubber insulation, G16 quality. The filler is a mixture of non-hygroscopic material and the outer sheath is a composite of R16 quality PVC. Of this

type are the cables: 3x2.5 with a weight of 182 kg/km, 3x35 with 1373 kg/km, 2x1.5 with 127 kg/km, 2x2.5 with 160 kg/km and 2x4 with 207 kg/km.

- SIHF-FG4G4: Class 5 red copper conductor, annealed or tinned, the insulation and sheath are made of silicone rubber, suitable for high temperatures, flame retardant and halogen-free. The cables are of this type: 4G1.5 with a weight of 133 kg/km, 4G2.5 with 201 kg/km, 4G4 with 307 kg/km, 4G6 with 440 kg/km and 4G16 with 1020 kg/km.

TOTAL AZ 53	
CODE	**MT**
CAV 1.5 WHITE	**24**
CAV 1.5 BLUE	**12**
CAV 1.5 GREY	**164**
CAV 1.5 BROWN	**16**
CAV 1.5 BLACK	**339**
CAV 1.5 RED	**515**
CAV 1.5 GREEN	**13**
CAV 10 BLUE	**8**
CAV 10 G/V	**22**
CAV 10 BROWN	**8**
CAV 10 BLACK	**11**
CAV 10 RED	**15**
CAV 12X0,50	**43**
CAV 16 BLUE	**16**
CAV 16 G/V	**8**
CAV 16 BROWN	**16**
CAV 16 BLACK	**34**
CAV 16 RED	**18**

CAV 16X1,5	**16**
CAV 2.5 BLUE	**44**
CAV 2.5 G/V	**44**
CAV 2.5 GREY	**52**
CAV 2.5 BROWN	**44**
CAV 2.5 BLACK	**279**
CAV 2.5 RED	**374**
CAV 25 G/V	**32**
CAV 25 BLACK	**19**
CAV 25 RED	**29**
CAV 35 G/V	**45**
CAV 35 BLACK	**32**
CAV 35 RED	**89**
CAV 3G1,5	**45**
CAV 3G2,5	**236**
CAV 3X0,50	**32**
CAV 3X2,5	**25**
CAV 3X35 FG7	**12**
CAV 4 BLACK	**74,5**
CAV 4 RED	**102,5**
CAV 4G1.5	**105**
CAV 4G16	**4**
CAV 4G16 FG7	**18**
CAV 4G2.5	**64**
CAV 4G4	**19**
CAV 4G6	**12**
CAV 50 BLACK	**19**
CAV 50 RED	**19**
CAV 6 BLACK	**64**
CAV 6 RED	**101**
CAV 70 G/V	**17**

CAV 70 BLACK	**34**
CAV 70 RED	**32**
CAV 7X1,5	**74**
CAV 8X0,50	**160**
CAV 95 BLACK	**40**
CAV 95 RED	**61**
CAV SAT703B	**40**
CAV SCH 2X0,50	**111**
CAV SPEC 2X1,5	**739**
CAV SPEC 2X2.5	**165**
CAV SPEC 2X4	**26**
TOTAL MT	**4832**

Table 2: list of cables used

6. POWER MONITORING

The project developed concerns the monitoring of the energy consumed by the loads inside the boat. This is crucial because, until now, a detailed view of the energy consumption of each individual load has never been obtained. It has come to this point because, starting to create electric prototypes and wanting to install lithium batteries, given their long life and energy efficiency, it is important to choose their capacity based on actual consumption, so as to be able to stay out of port and guarantee autonomy even for several days without turning on the generator.

If to make the sizing of a system for civil and industrial use there are coefficients of use and contemporaneity, in the nautical sector, having lower numbers, these coefficients do not exist or are dated.

The objective of the work is therefore to make a statistic of how much and how the loads are used during navigation and at anchor, to provide the customer with the actual autonomy of the battery in both cases.

The problem was addressed by considering the Power Monitoring solutions proposed by Schneider Electric in collaboration with CIM 4.0 and ABB, but due to shorter timelines, the former was chosen. However, both projects and their respective problems will be illustrated.

6.1 SCHNEIDER ELECTRIC'S PROPOSAL

The ***PowerTag*** ecosystem is an optimized energy monitoring system, equipped with wireless energy sensors, control devices and PowerTag Link gateways that integrate to offer a view of how energy is used at all levels, with regard to the alternating current circuit only, as it is designed for civil and industrial applications.

The sensors used are the PowerTag E 63A, energy sensors that provide real-time measurements of voltage, current, power factor, active power and apparent power at the point where they have been installed. The installation is done directly on the protection device and they can record a maximum current of 63 A, which is sufficient for these types of loads, but it may not be enough if you extend the design to other loads.

The sensors used in this application are the A9MEM1521 model and the A9MEM1560 model, both of which are single-phase sensors.

The first is integrated directly under the switch and has dimensions 16.5x36x43 (mm), the second is applied around the conductor and has dimensions 20x18x44.5 (mm).

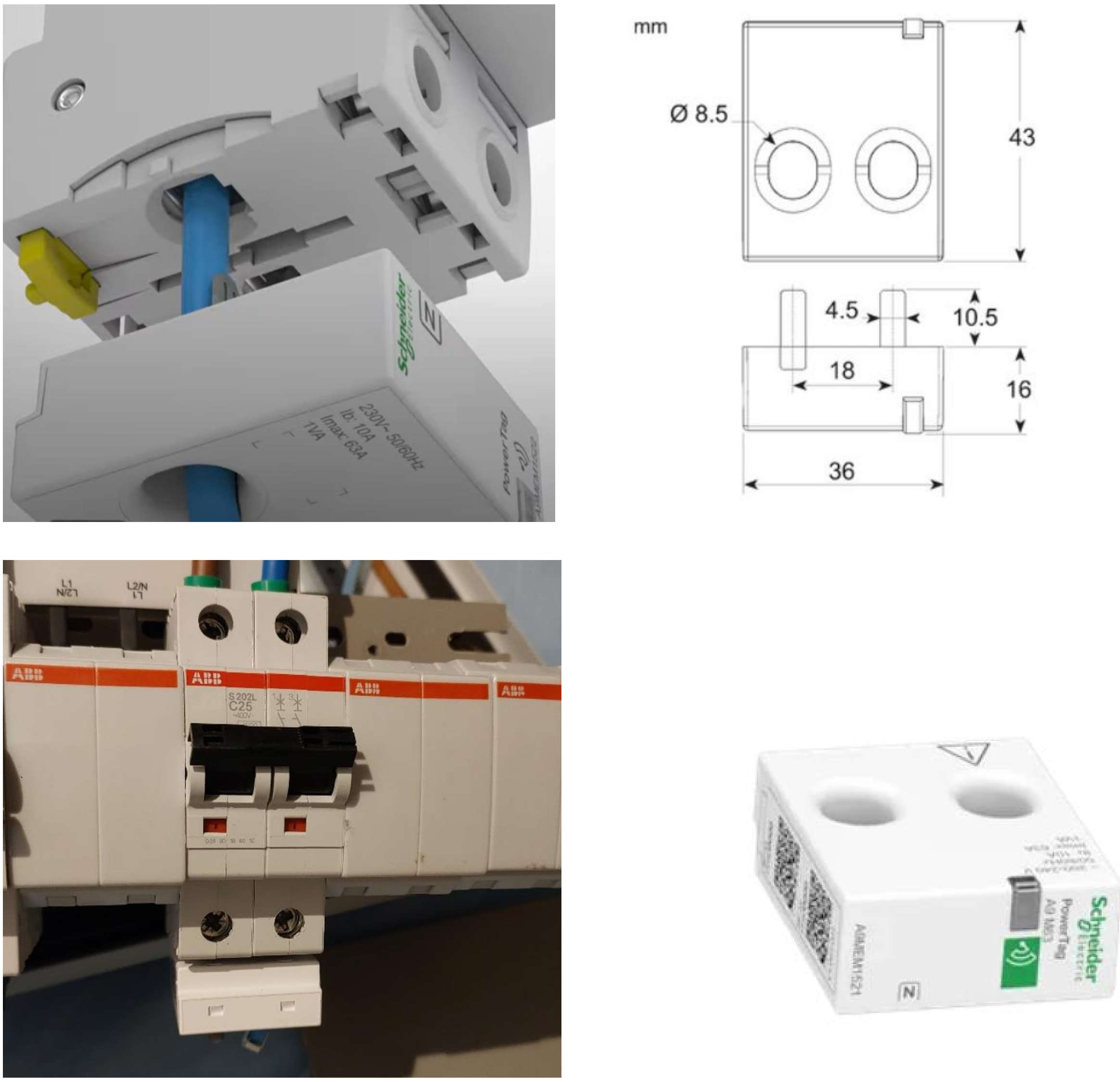
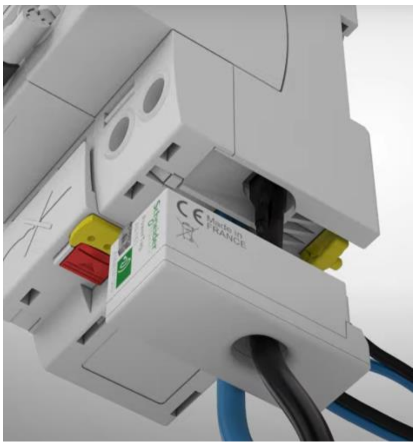


Figure 28: A9MEM1521 sensor



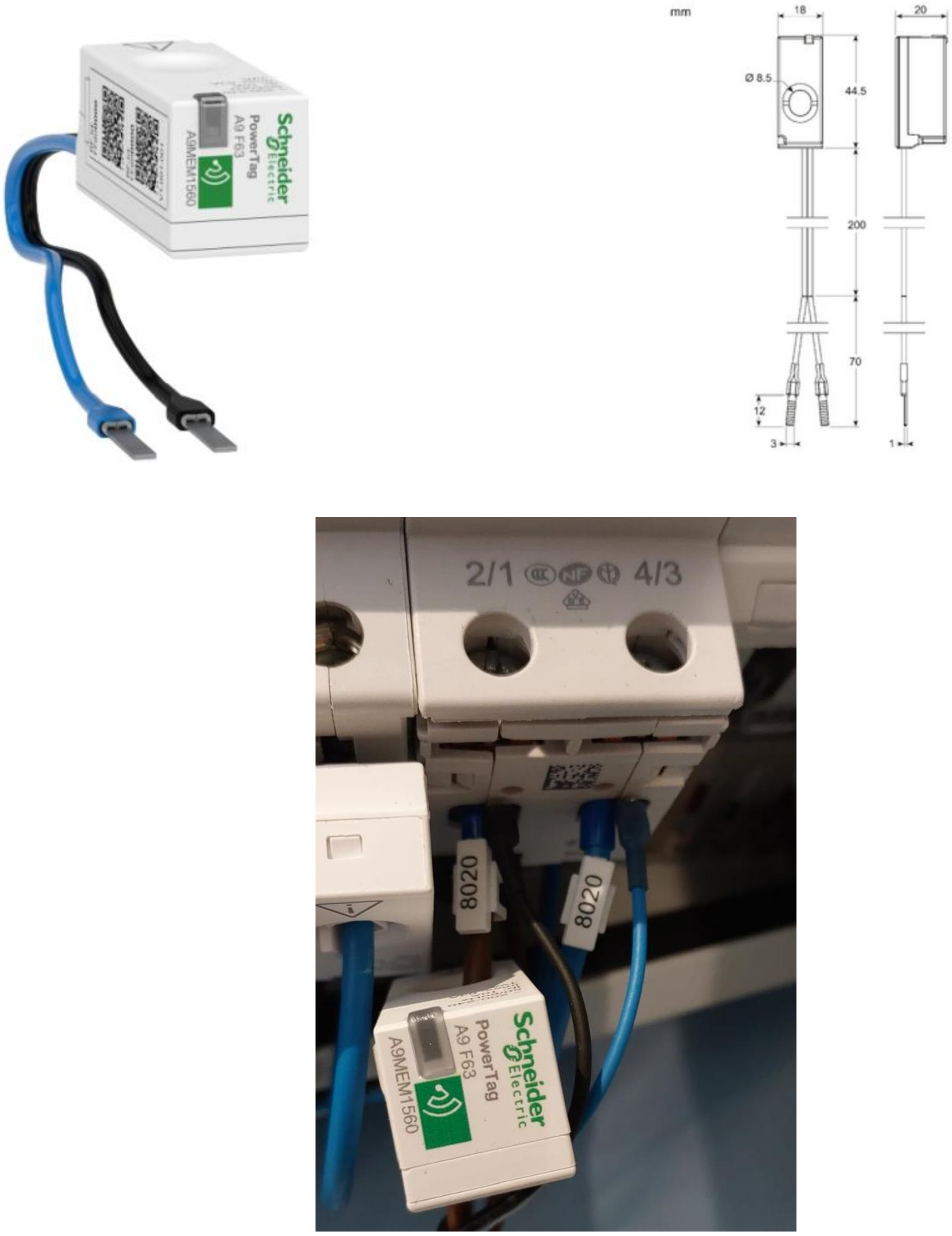


Figure 29: A9MEM1560 sensor

The PowerLink Gateway is a communication device that acts as a wireless concentrator, designed to monitor and measure electrical parameters within the panel in real time. It then receives information, such as energy, power, voltage, current and power factor, from the sensors described above via wireless. [13]

Figure 30:PowerLink Gateway

The data received are transmitted to the management software, via router, with a sampling frequency of one reading every ten seconds, allowing it to be subsequently displayed in the form of a database of all the data collected over time.

Figure 31:Router

The loads to be monitored in the AC sub-panel on the dashboard are:

- Main battery charger
- Range
- Gallery exhaust

- Boiler
- Fridges
- Oven
- Dishwasher
- Genset batteries charger

Figure 32:AC loads to be monitored in the dashboard

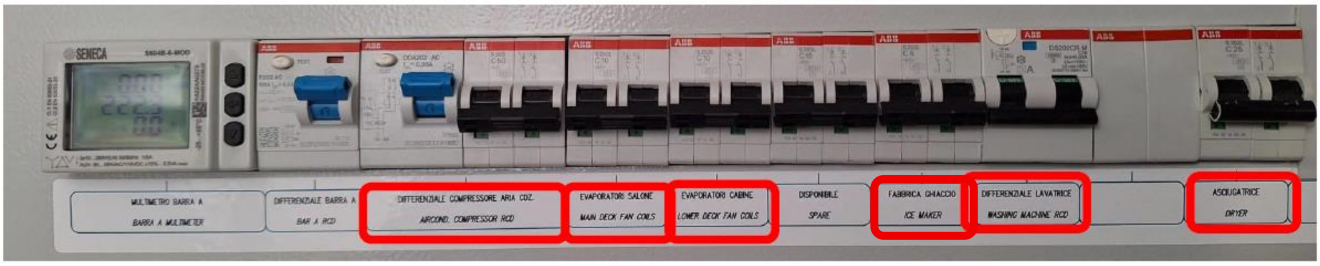
The loads of the A bar to be monitored in the QAC1 present in the crew cabin are:

- Comprex A/C
- Main deck fan coils
- Lower deck fan coils
- Washing machine
- Dryer
- Fly ice maker

The loads of the B bar to be monitored in the QAC1 present in the crew cabin are:

- Comprex A/C

- Saloon board
- Barbecue
- Stabilizer



CARICHI DA MONITORARE BARRA A
- COMPREX A/C
- EVAPORATORI SALONE
- EVAPORATORI CABINE
- LAVATRICE
- ASCIUGATRICE

CARICHI DA MONITORARE BARRA B
- COMPREX A/C
- QUADRO SALONE
- BBQ
- STABILIZZATORE

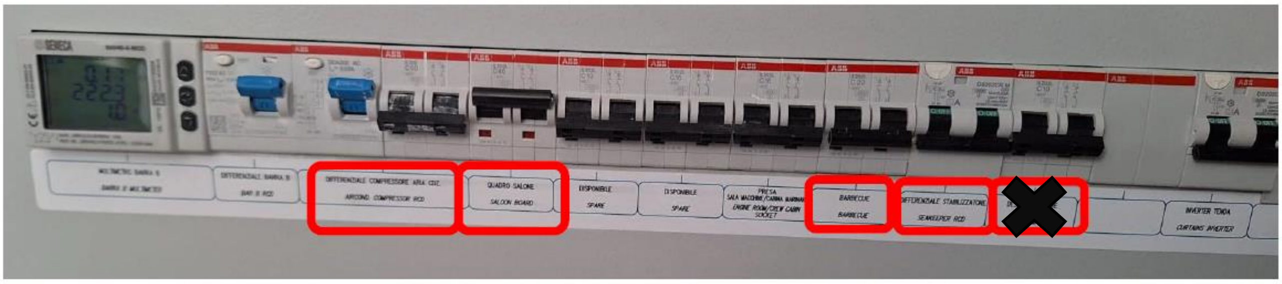


Figure 33:A bar and B bar loads to be monitored in the crew cabin

6.2 SCHNEIDER ELECTRIC POWER MONITORING INSTALLATION

In the crew cabin, in the QAC1, Gateway n. 1 and ten sensors have been installed, some of A9MEM1560 model and others A9MEM1521. Specifically, six to monitor the loads of bar A and four to monitor those of bar B, previously listed.

Figure 34:A bar and B bar in the crew cabin

Figure 35:Six sensors mounted on the A-bar

Figure 36:A9MEM1521 sensor

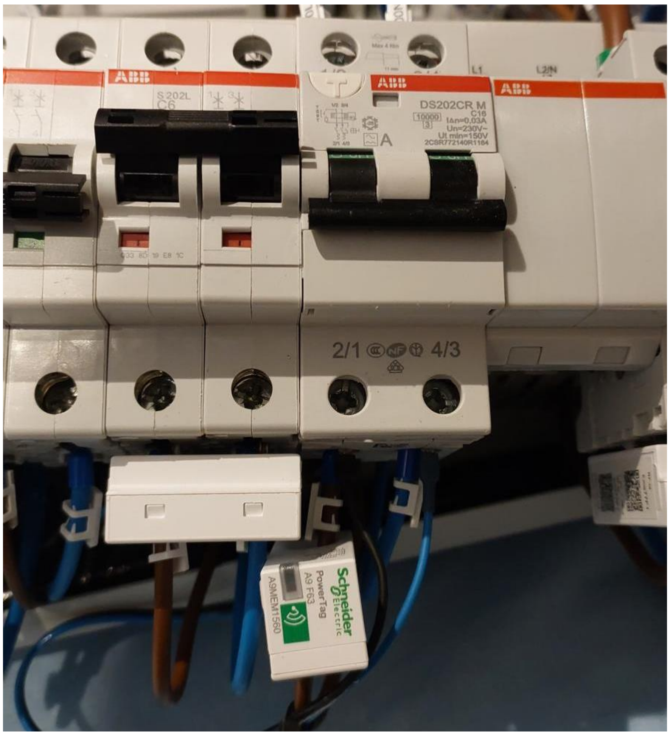


Figure 37:Left sensor A9MEM1521, right A9MEM1560

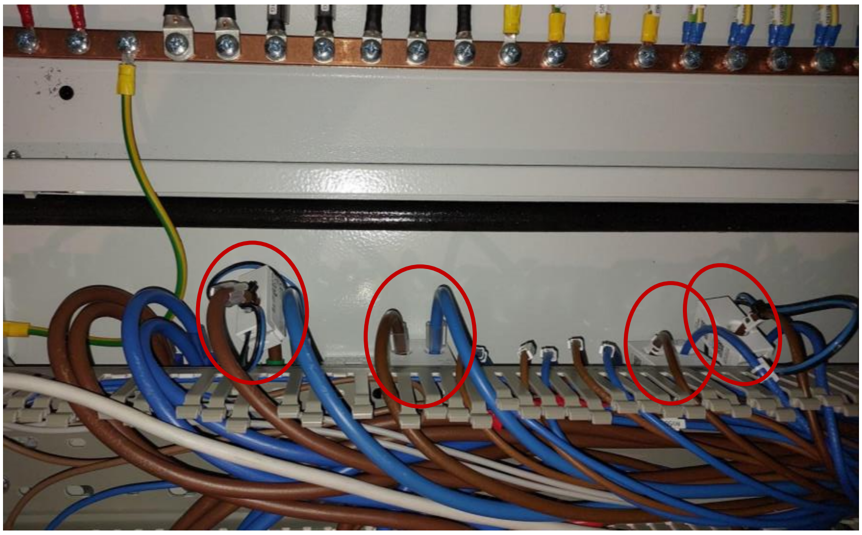


Figure 38:four sensors mounted on the B bar

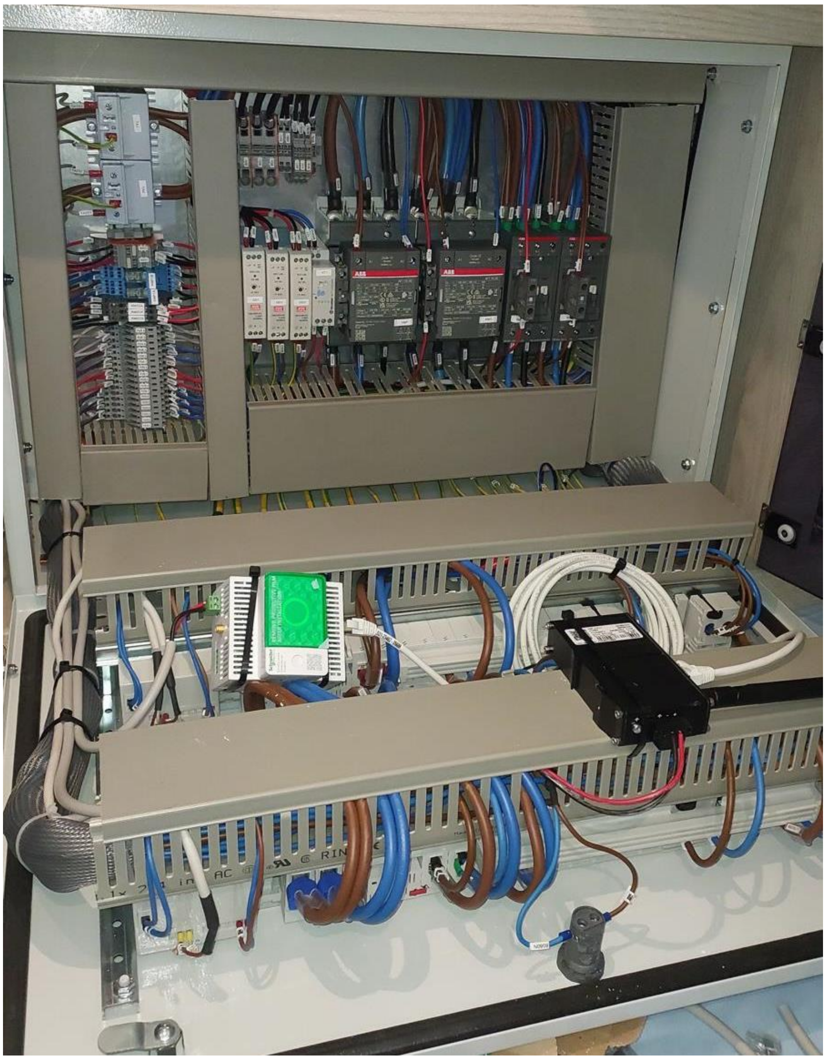


Figure 39:AC panel architecture in the crew cabin

In the AC under-panel area on the dashboard, 8 current sensors were installed, four of model A9MEM1521 and four A9MEM1560, and Gateway nr.2. Also in this area, the Schneider Control Unit was installed directly wired with Gateway nr.2 and in connection with the NMEA-2000 system through a Gateway for NMEA2000 interface.

Figure 40: bridge area where the architecture is mounted

Figure 41: bridge area where the architecture is mounted

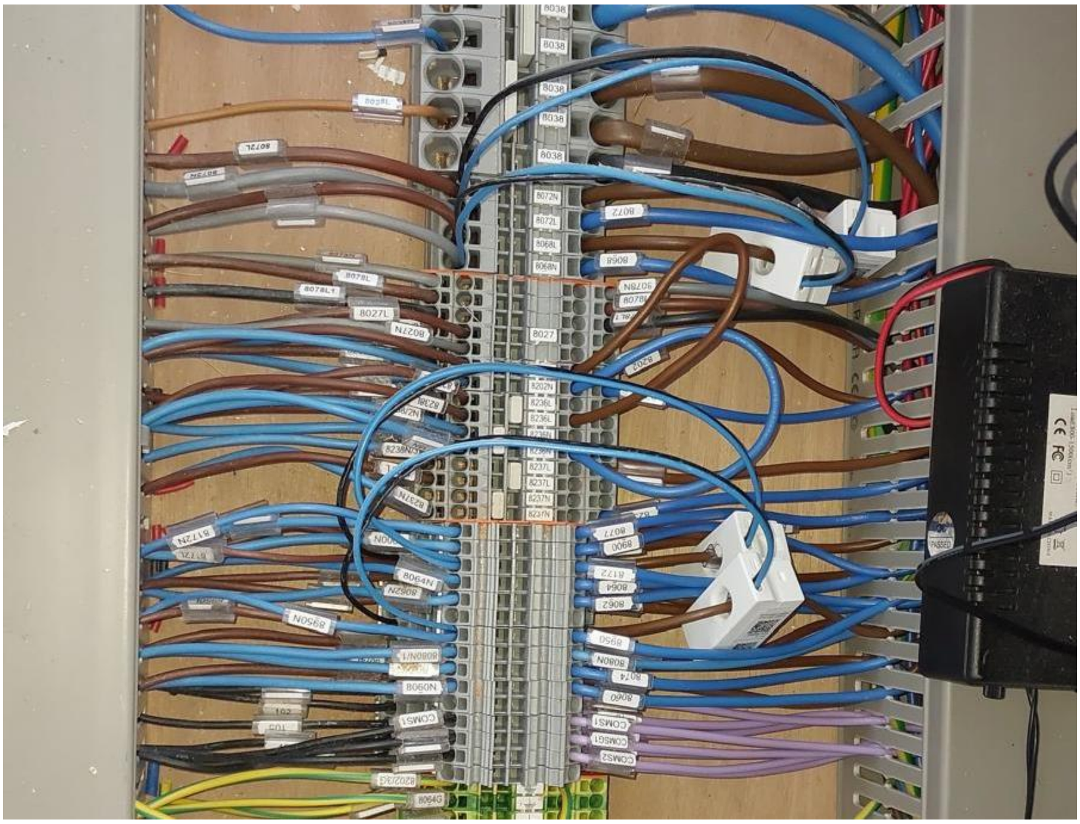


Figure 42: four A9MEM1560 sensors

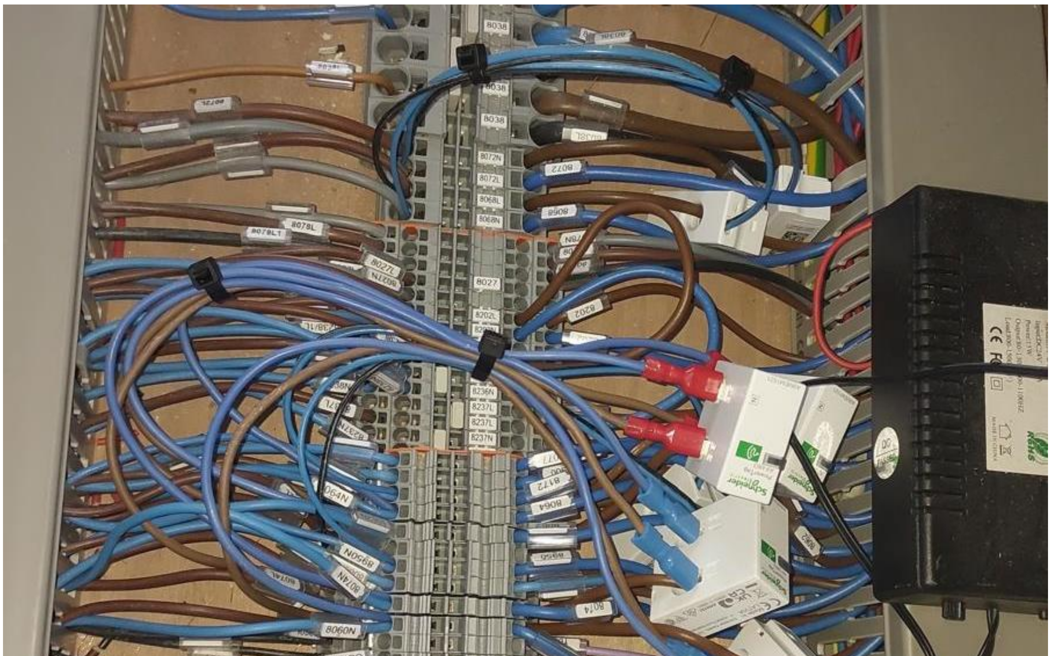


Figure 43:four A9MEM1560 sensors and four A9MEM1521

Figure 44:gateway in the bridge area

The Schneider Control Unit performs control logic, trend logging, supports communication and connectivity with I/O and fieldbuses. It integrates Modbus TCP client and server, which is why a NMEA2000/Modbus TCP Gateway is required to allow the connection between Garmin and the Schneider Control Unit. It collects and stores all data, with a memory of 4 GB, and via wi-fi sends this to the server developed by CIM 4.0.

Figure 45:Control Unit Schneider

The power supplies are 230 V for the sensors and 24 Vdc for the Control Unit and the repeater, under the inverter service battery switch.

In the initial project, for the transmission between Gateway n. 1 located in the crew cabin and the Control Unit, a repeater was to be placed in the saloon area in case of too weak a signal. In fact, after the test phase, a fairly strong signal was noticed that did not need any repeater; therefore, only one access-point was placed in the crew cabin and two access-points in the saloon.

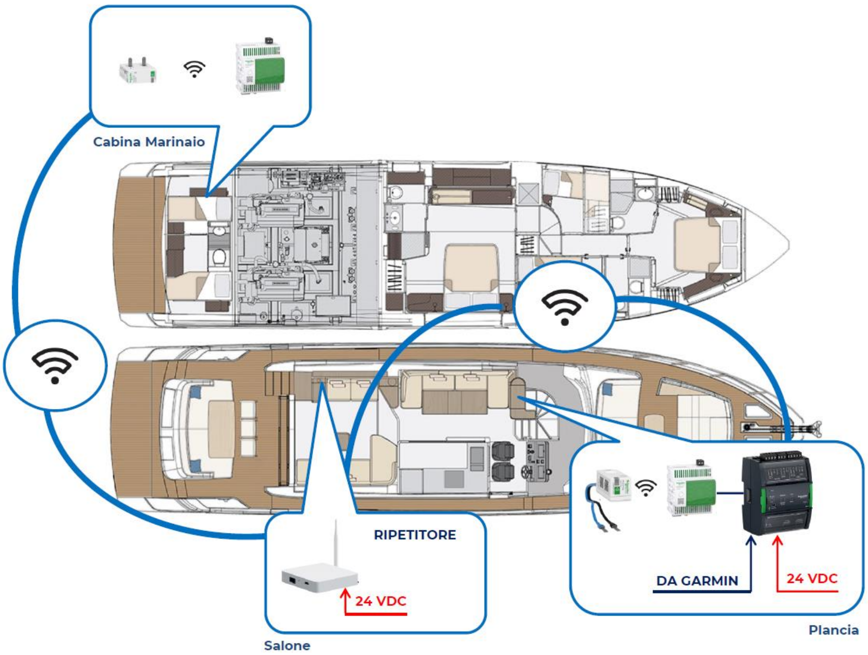


Figure 46: initial design

Therefore, the Control Unit is connected to Gateway n. 1 through the access point, to Garmin through Gateway NMEA2000/Modbus-TCP and is directly wired to Gateway n. 2.

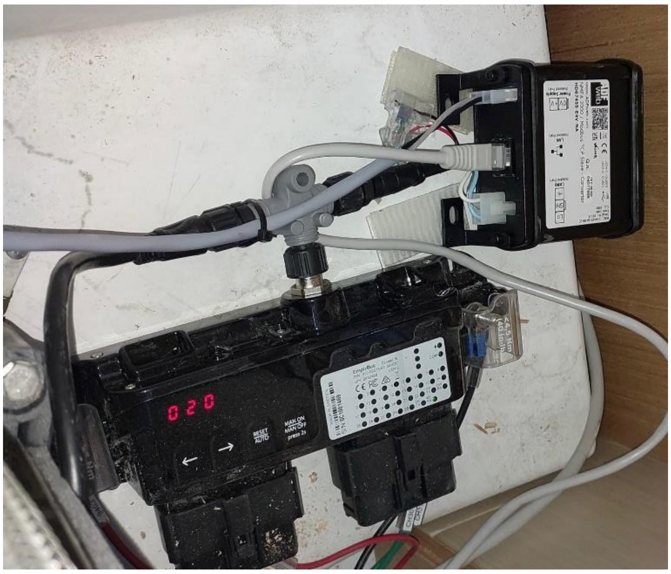


Figure 47: NMEA2000/Modbus TCP gateway

Being a communication via wi-fi, it was necessary to install Starlink in the boat, so that the data is saved and downloaded to the server and then analyzed.

It is a satellite Internet provider that enables broadband, high-speed, low-latency connectivity around the world, even offshore, where connectivity is unreliable.

The data from Garmin is essential as some, such as speed and GPS position, allow you to understand whether the boat is moving or stationary.

They are communicated through PGNs, an acronym for Parameter Group Number, numerical codes identifying the type of message transmitted on the NMEA-2000 network. Some of the PGN information used is standard, i.e. it can be obtained from any NMEA-2000 certified sensor, such as [28]:

- Engine parameters: alternator voltage, fuel rate, load, % torque and rpm, derived from standard PGNs 127488 and 127489

127488 Engine Parameters, Rapid Update

Provides data with a high update rate for a specific engine in a single frame message. The first field provides information as to which engine.

Field #	*Field Description*
1	Engine Instance
2	Engine Speed
3	Engine Boost Pressure
4	Engine tilt/trim
5	Reserved Bits

127489 Engine Parameters, Dynamic

Used to provide real-time operational data and status relevant to a specific engine, indicated by the engine instance field. This message would normally be broadcasted periodically to provide information for instrumentation or control functions.

Field #	*Field Description*
1	Engine instance
2	Engine oil pressure
3	Engine oil temp.
4	Engine temp.
5	Alternator potential
6	Fuel rate
7	Total engine hours
8	Engine coolant pressure
9	Fuel Pressure
10	Not Available
11	Engine Discrete Status 1
12	Engine Discrete Status 2
13	Percent Engine Load
14	Percent Engine Torque

Figure 48: Engine data from PGNs 1277488 and 127489

- GPS speed and position data, which can be obtained from PGN 129026, from which COG (Course Over Ground) and SOG (Speed over Ground) can be obtained.

129026 COG & SOG, Rapid Update

This parameter group is a single frame parameter group that provides Course Over Ground (COG) and Speed Over Ground (SOG)

Field #	*Field Description*
1	SID
2	COG Reference
3	Reserved Bits
4	Course Over Ground
5	Speed Over Ground
6	Reserved Bits

Figure 49: COG and SOG data from the PGN 129026

As for data such as the on/off states of the electrical source, extractors, air conditioning and the fan speed of the various environments, it was necessary to create custom PGNs, as this information is not always available in every device, but specific for this application.

All the measurements read through PGN custom are shown in the table.

Measure to read	User	PGN	Instance	Type
Current	BAR A	127503	0	
Tension	BAR A	127503	0	
Frequency	BAR A	127503	0	
Current	B BAR	127503	1	
Tension	B BAR	127503	1	
Frequency	B BAR	127503	1	
Room temperature	Salon	130312	1	Internal Temperature (2)
Temperature Setpoint	Salon	130312	1	Internal Temperature (2)
Room temperature	Kitchen	130312	2	Internal Temperature (2)
Temperature Setpoint	Kitchen	130312	2	Internal Temperature (2)
Room temperature	Wheelhouse	130312	3	Internal Temperature (2)
Temperature Setpoint	Wheelhouse	130312	3	Internal Temperature (2)
Room temperature	Guests Straight	130312	4	Internal Temperature (2)
Temperature Setpoint	Guests Straight	130312	4	Internal Temperature (2)
Room temperature	VIP	130312	5	Internal Temperature (2)
Temperature Setpoint	VIP	130312	5	Internal Temperature (2)
Room temperature	Guests Left	130312	6	Internal Temperature (2)
Temperature Setpoint	Guests Left	130312	6	Internal Temperature (2)
Room temperature	Shipowner	130312	7	Internal Temperature (2)
Temperature Setpoint	Shipowner	130312	7	Internal Temperature (2)
Room temperature	Sailor	130312	8	Internal Temperature (2)
Temperature Setpoint	Sailor	130312	8	Internal Temperature (2)
Altitude	GPS	129025		
Longitude	GPS	129025		
Current Discharge	Batteries Services	127508	0	
Charging Current	Batteries Services	127508	1	
Tension	Batteries Services	127508	0	
Tension	Generator Batteries	127508	2	
Tension	Bow Thruster Batteries	127508	3	
Level	Fresh Waters	127505	0	Fresh Water (1)
Level	Black Water	127505	0	Black Water (5)
Level	Grey Water	127505	0	Grey Water (2)
Level	Fuel	127505	0	Fuel (0)

Table 3: PGN custom

This information can also be read on the Garmin display located in the wheelhouse station.

Figure 50: info available on Garmin display

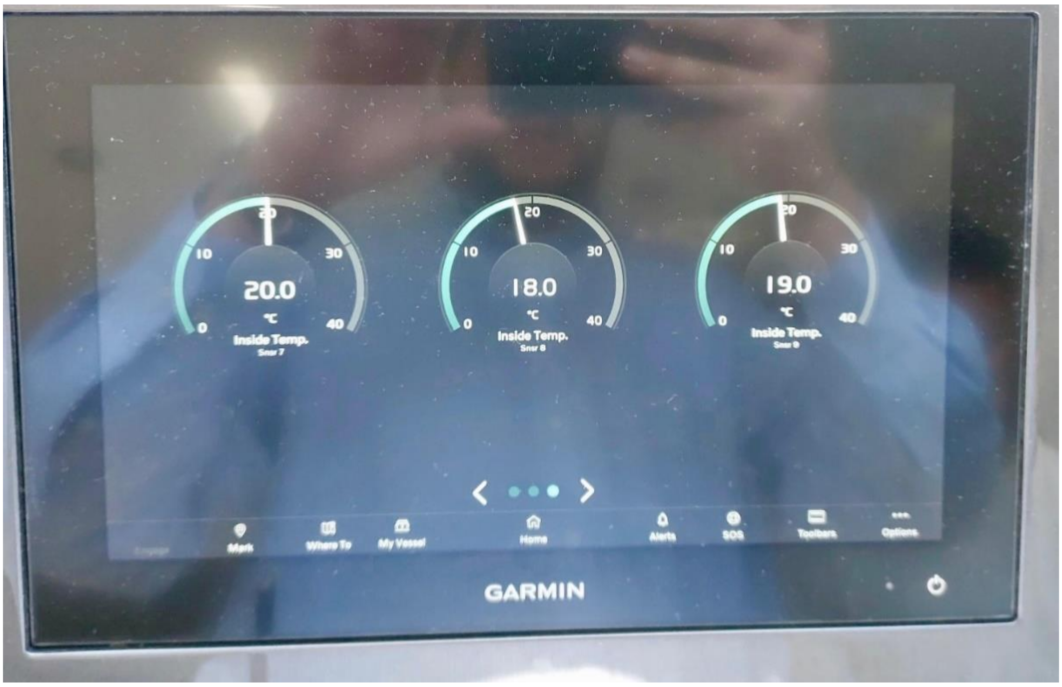


Figure 51 :info available on Garmin display

Figure 52: info available on Garmin display

Figure 53: info available on Garmin display

6.3 PROJECT LIMITATIONS

The advantage of this project is certainly communication via wi-fi, but as explained above, some of the boat's loads are powered by direct current and others by alternating current. A limitation of this model is certainly the inability to read direct current loads, as it is a project created for the civil and industrial sector in which it is present.

Therefore, the consumption of direct current loads remains unknown.

6.4 ABB'S INSITE ENERGY MANAGEMENT PROPOSAL

InSite is a current, voltage, power and energy measurement system, suitable for monitoring both alternating and direct current circuits.

It is a webserver system, therefore, it has a memory inside that is populated over time and can integrate different types of information, typically all the measurements that can be made with T.A. or even with other tools that will then be integrated. It can also monitor the states of the circuit breakers to know which circuit is open, if it is open due to fault or manual movement, it already has automations, so if you go above thresholds or have an event such as the trip of a switch, you can command an action.

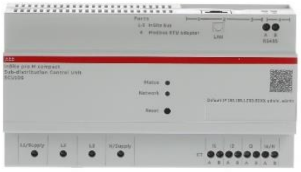
The components are:

- Control unit: analyzes the various data collected by the sensors and makes them available via the built-in interfaces. The two units available are the SCU100 and the SCU200.

  SCU100 is 7-module, SCU200 is 2-module. The power supply for the 100 is 230 V, while for the 200 it is 24 Vdc, the best choice in the nautical field.

Figure 54: SCU200

Figure 55: SCU100

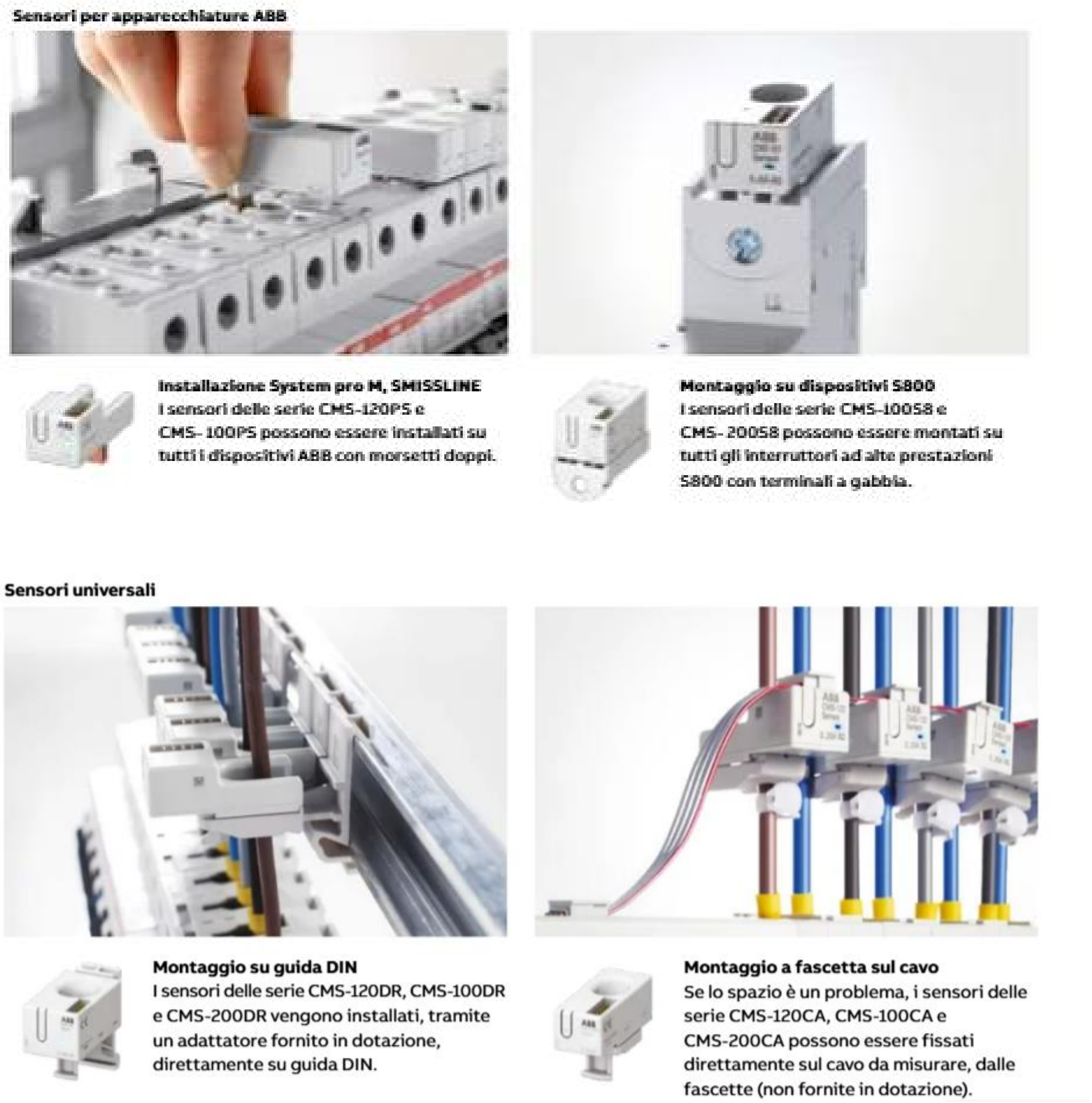


- CMS bus interfaces: Each interface allows the connection of up to 96 total sensors for the SCU100 and up to 32 total sensors for the SCU200, the disadvantage of the SCU-100 is the larger space occupied.
- Connection technology: The sensors are connected to the control unit via a flexible flat cable and insulation displacement connectors. The positioning of the sensors is customizable, and they can be placed at the exact point where a measurement is required. This BUS, however, is neither shielded nor twisted, creating problems in terms of disturbances. If energy-intensive utilities were turned on, thus creating a significant magnetic field, the bus would absorb everything, creating noise.

Figure 56:BUS

- CMS sensors: they measure both direct and alternating current and can be installed anywhere, assigning an identification number to each sensor via the control unit. They are adaptable to both ABB devices and universal devices. There are different sizes and for different currents, up to 160 A.

Figure 57: CMS Sensors



- Serial interface: Depending on the control unit chosen, RS485 and LAN interfaces are available. An Internet browser is used to view the measured values and they can be exported in CSV format.

Figure 58:design

The project involved the use of four SCU200s, one in each of the four panels, as the maximum number of devices that can be connected to each is 32 and communication between them is in Modbus TCP.

The SCU-200 stores and records all data every five seconds thanks to its 3 GB memory expandable up to 200 GB and then transfers it to the server and makes it possible to view the consumption report of the recorded loads every thirty seconds. [15]

The main problem of this solution, which has not been solved due to timing, is that this system with the SCU200 control unit is not able to connect to the Garmin and Schneider system through the RS-485 port, as it is currently dedicated to the integration of devices with Modbus RTU communication but cannot be used to communicate with Modbus RTU to a higher supervision system. One solution would have been to consider the SCU100, then be able to use only one and not four like the SCU200, thanks to its ability to connect up to 96 sensors. In fact, the SCU100 has two RS-485 ports, of which port 5 can be used to communicate via Modbus RTU to a higher supervision system, but evaluating the disadvantage of having a 230 V power supply and a larger occupied space.

7. LIGHTING SYSTEM

In the current lighting panel, there are the power feeding lines of the light circuits: owner's cabin, VIP cabin, guest cabin and corridor. Characteristic electromechanical elements in this panel are relays and fuses.

Figure 59: Current lighting panel

In particular, relays:

A. Hallway lights

B. Step lights

C. Owner's lights

D. Owner's lights

E. Guest Lights

F. Guest lights

G. VIP Lights

H. VIP Lights

The purpose of the study is to evaluate the possibility of modifying the current lighting panel, replacing the electromechanical elements inside the panel with an electronic control unit, evaluating the economic and weight effects (in this specific case, a Garmin control unit was selected).

There are two projects developed: one involves the use of KNX technology, the other ENocean technology. The respective advantages and disadvantages will be discussed.

7.1 GARMIN BOAT SWITCH AND NMEA2000

In both projects, the common element is the presence of the Garmin control unit inside the electrical panel, replacing relays and fuses. In this way, space and weight are reduced, considering that the control unit has a weight of 400 grams and the following dimensions:

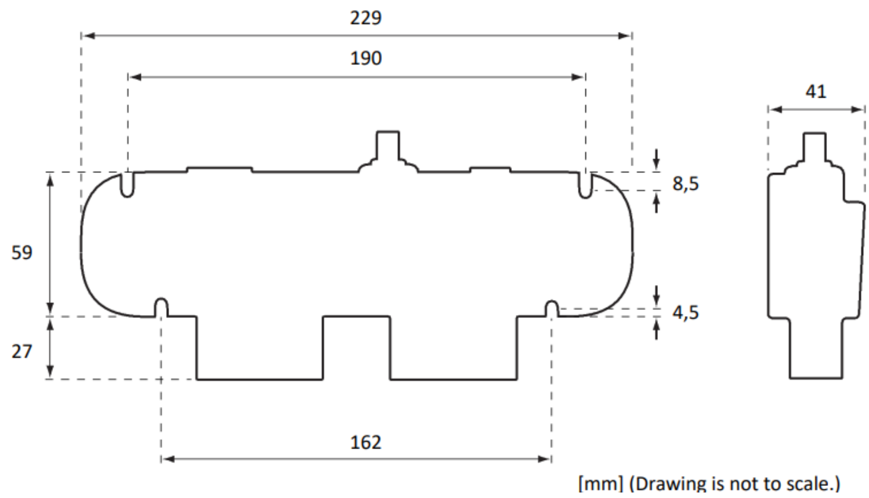


Figure 60: Garmin Boat Switch dimensions

Replacement is possible thanks to EmpirBus technology, a Digital Switching system developed by Garmin that allows you to control all the on-board electronic systems via a customizable user interface.

In practice, EmpirBus replaces traditional electromechanical elements with a network of electronic devices that manage the distribution of electrical energy and data transmission. [16]

Crucially, its plug-and-play communication protocol[1] NMEA2000[2] used to connect marine sensors and display devices inside ships and vessels, thanks to requirements based on CAN communications. The standard describes a low-cost, moderate-capacitance, bidirectional multi-transmitter/multi-receiver instrument network for interconnecting marine electronic devices.

Equipment designed to this standard can share data, including commands and status, with other compatible equipment on a single channel. All products that read and/or transmit NMEA 2000 information must be certified by NMEA.

The first NMEA-certified products date back to 2004, while the protocol currently enjoys recognition from the Society of Automotive Engineers, the SAE, as a standard for marine data communication.

One of NMEA2000's strengths is certainly its open architecture, from which the fast interoperability between motors, sensors and instruments derives. It ensures the networking of communication GPS, motors, monitors, alarms and a marine fuel flow meter, which can thus be controlled on a single system.

The other advantages concern the ability to connect products of different brands brought together in a single language and the reduction in the number of cables required.

---

[1] Once connected, there is no need for additional configuration

[2] acronym for National Marine Electronics Association

Before NMEA2000, the reference standard was NMEA0183, which had the defect of being based on point-to-point connections: it was necessary for the various devices to be connected to each other one by one. This problem does not concern NMEA2000 because it supports multiple connections that connect the various devices through a single network, i.e. the latter transmit the data over the network and read it quickly.

Another difference lies in the type of messages used: NMEA0183 used text messages, NMEA2000 uses binary messages.

In the NMEA2000 standard, it is not necessary to set up data transfer rates and select communication ports. There is no need to connect wires one by one, you just need to connect the instruments and sensors that will be instantly detected in the network.

The bus power supply makes it possible to connect the stand-alone sensors directly to the network. The temperature, GPS, fuel level and depth sensors can all be connected to a single bus using the power available in the network, even on small boats. [17]

7.2 ENOCEAN PROJECT

EnOcean technology is an energy harvesting process, i.e. a process by which energy, coming from alternative energy sources over time, is captured and saved.

Sensors and switches collect energy from the surrounding environment and are self-powering, allowing the use of energy-autonomous control systems; therefore, they do not involve the presence of batteries or cables, but derive energy from movement, light and temperature differences. The principle of energy harvesting is not only a cost-effective but also sustainable alternative that requires no maintenance.

The project includes EnOcean technology with the Garmin control unit inside the light panel, replacing the electromechanical part of the current panel, and the two-module EnOcean buttons positioned directly on the walls.

The benefit of reduced wiring and space is obvious.

7.2.1 OPERATION OF THE ENOCEAN BUTTONS

Pressing a button releases enough energy to turn on the lights, thanks to the presence of an energy converter inside the switching modules. The converter is electromechanical and uses kinetic motion to generate energy and send a telegram.

Although these amounts of energy collected are small, they are sufficient to transmit and receive wireless signals and allow the operation of maintenance-free sensors.

The ECO200 converter used in the case of pressing a switch transforms mechanical energy into electrical energy. It works like a dynamo and makes energy immediately available. With a power output of 120 µWs and a battery-free wireless module, three radio telegrams can be transmitted per operation. It allows a completion of 300,000 switching cycles; Under ideal conditions, more than one million switching cycles are possible.

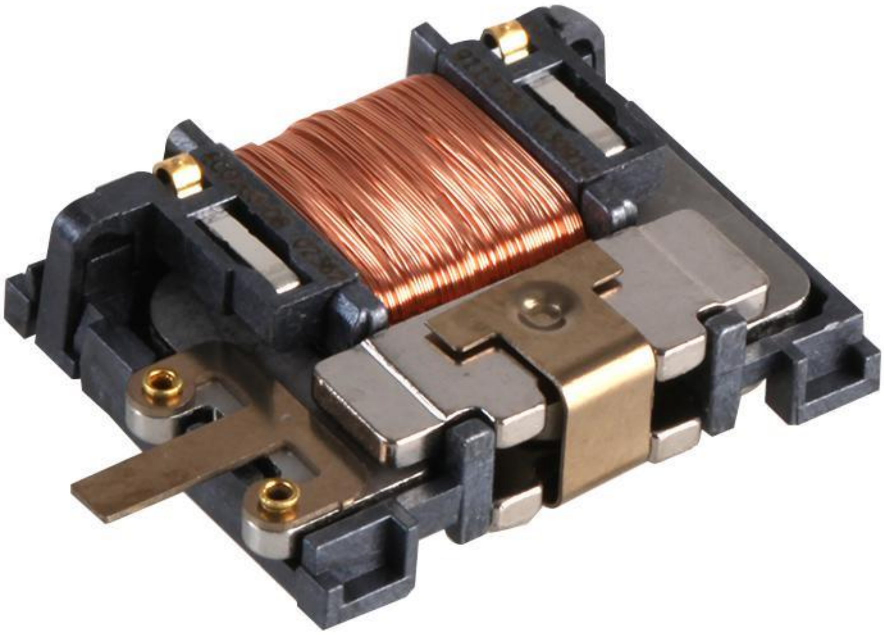


Figure 61: EnOcean operation

The EnOcean radio standard is internationally standardized as ISO/IEC 14543-3-1X and can therefore be used anywhere, such as Wi-Fi or Bluetooth. RF reliability is guaranteed because the sent telegram has a duration of less than one millisecond and a data transmission rate of 125 kbit/s. Telegrams are randomly repeated twice within 40 milliseconds to ensure a low probability of collisions between the final telegrams and seamlessly manage numerous switches and sensors in parallel. Each EnOcean radio module has a unique 32-bit identification number that ensures high transmission reliability, as it cannot be modified or copied and protects against duplication.

For optimal RF effectiveness, the radio protocol uses frequency bands below 1 GHz: 868 MHz for the European Union according to CE/RED regulations and for the United Kingdom according to the UK/CA, 902 MHz for the USA according to FCC specifications and for Canada according to IC specifications and 928 MHz in Japan according to ARIB. These radio waves can easily penetrate walls and have a high transmission power, they can be transmitted up to 300 meters outdoors and up to 30 meters inside buildings. Eventually there is the possibility of inserting a repeater to extend the range. There are also solutions that use the 2.4 GHz frequency band open worldwide, the range of which is about 10 meters in the closed field and 100 meters outdoors, for this reason it is more suitable for single-room cases, where high penetration through walls is not required.

The sensors have standardized wave profiles to ensure interoperability between products of different brands, for example sensors from one manufacturer with receivers and control units from another.

Early designs used piezoelectric generators, which were later replaced by electromagnetic generators to reduce the force required for their operation and increase their useful life.

Another advantage is the presence of different models, from the simple on/off switch to the slide and rotary control to control the intensity and color of the light. Currently, the study stops at the lighting system, but this technology also works for window contact sensors that signal when a window is open or for water sensors, using an expandable material that activates the electromechanical energy converter. [18][19]

7.2.2 ENOCEAN MODULES

For aesthetic and commercial reasons, the controls and buttons of the VIMAR brand are taken into consideration. In particular, the EnOcean radio control is a four-button flat control with 868 MHz radio frequency transmitter, EnOcean standard, energy harvesting power supplied by the built-in electrodynamic generator, two modules.

The installation can be recessed or wall-mounted and the latter is possible on materials such as wood and masonry, thanks to the special support.

This module specifically has a range of 70m in the free field, which however is reduced in the presence of metal plates, concrete or metal walls. [20]

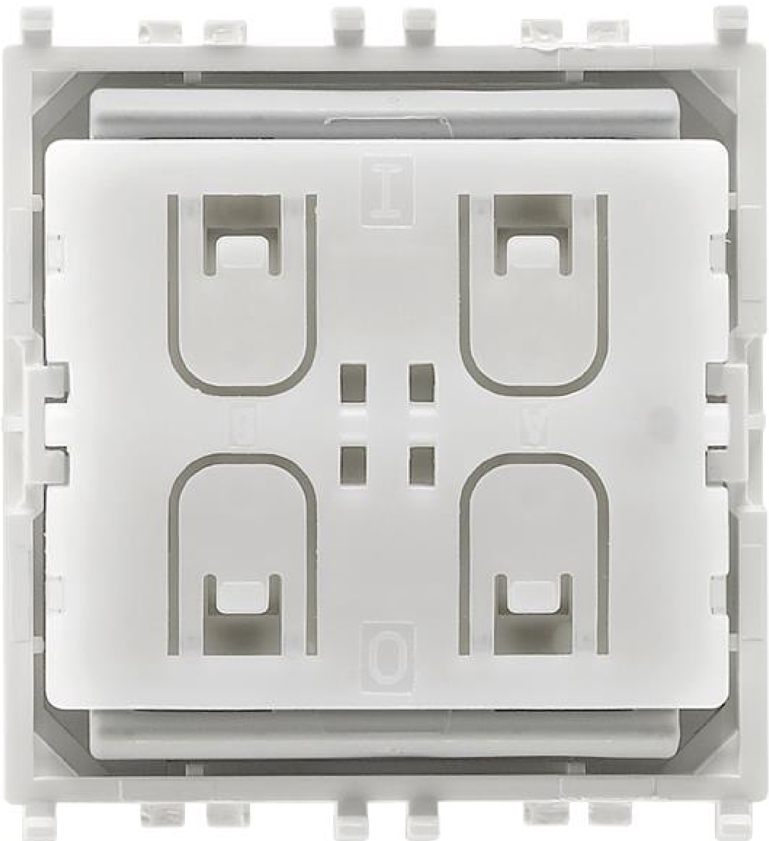


Figure 62: EnOcean Control

7.3 KNX PROJECT

KNX is a communication protocol that makes buildings smart and interoperable and is a globally recognized standard by more than 400 manufacturers, approved according to the EN50090 standard and ISO/IEC 14543.

All KNX products, regardless of the manufacturer, are certified by the Association which guarantees their compatibility.

The project involves the presence of the Garmin CU inside the light box, a NMEA2000-KNX converter, in order to allow communication between the two protocols and then the KNX power supply at the beginning of the network.

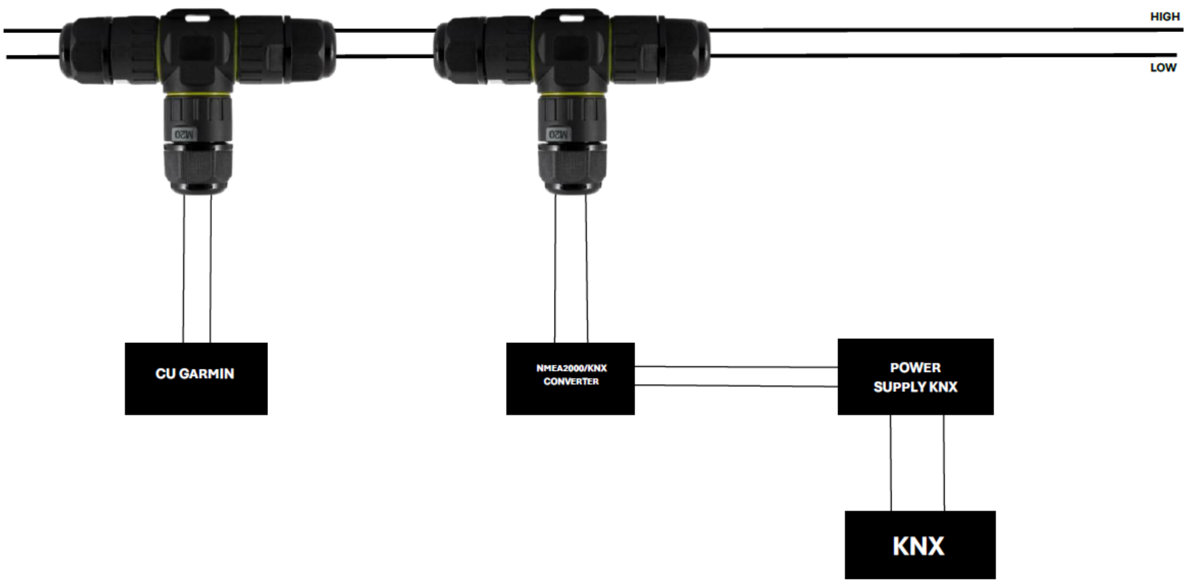


Figure 63: KNX Project

7.3.1 KNX ARCHITECTURE

The basic element of each KNX system is the line, which requires at least one power supply, sized according to the number of devices to which it is connected. Up to 64 devices can be connected to each line and, through line couplers, up to a maximum of 15 lines can be connected.

A system can comprise up to a maximum of 15 areas connected to each other by means of area or field couplers. The power supply necessary for the operation of the devices and the data signal is conveyed by the same bus cable which is a twisted pair and connects the KNX devices, which is also certified.

To avoid telegram collision and data loss, the CSMA/CA protocol is used[3].

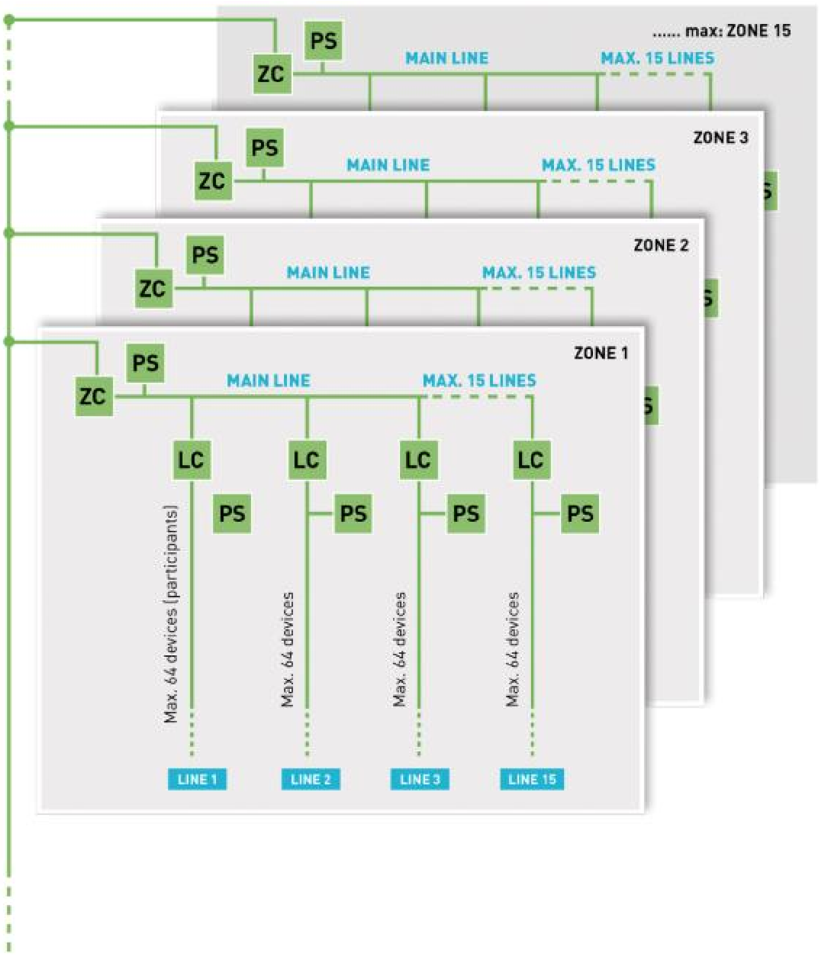


Figure 64: KNX organization

There are several topologies: series, star, tree, or mixed configuration, but all of them must adhere to the following constraints:

[3] Carrier Sense Multiple Access/Collision Avoidance

- Maximum cable length between the power supply and the bus device: 350 meters.
- Maximum length of the line between two bus devices: 700 meters.
- Total length of all cables within a line: 1,000 meters.
- Maximum number of power supplies on the same line: 2 (at least 200 meters apart).

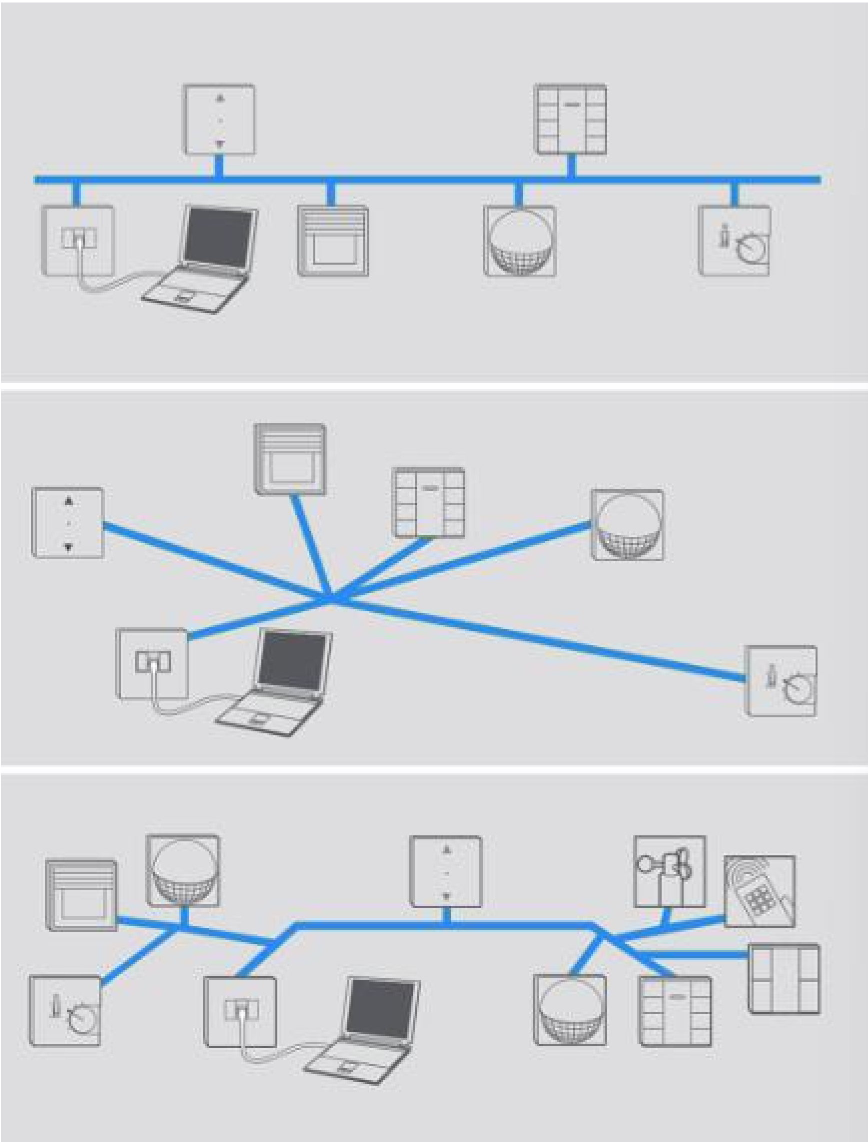


Figure 65: KNX topologies

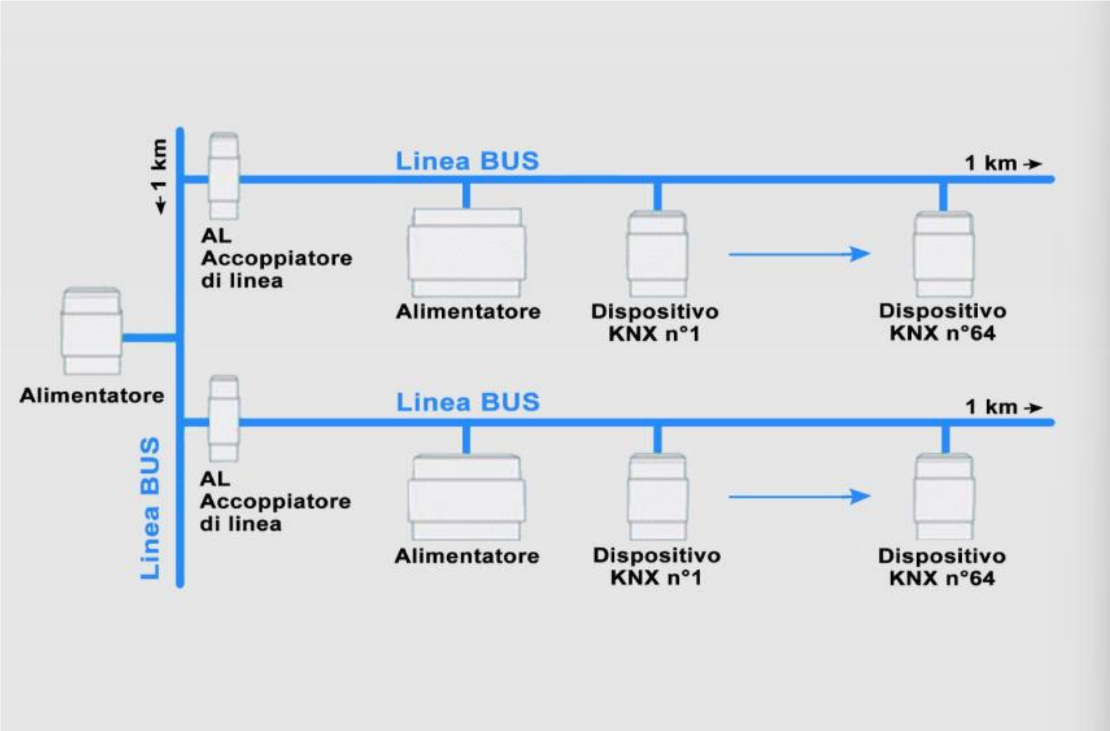


Figure 66: KNX architecture

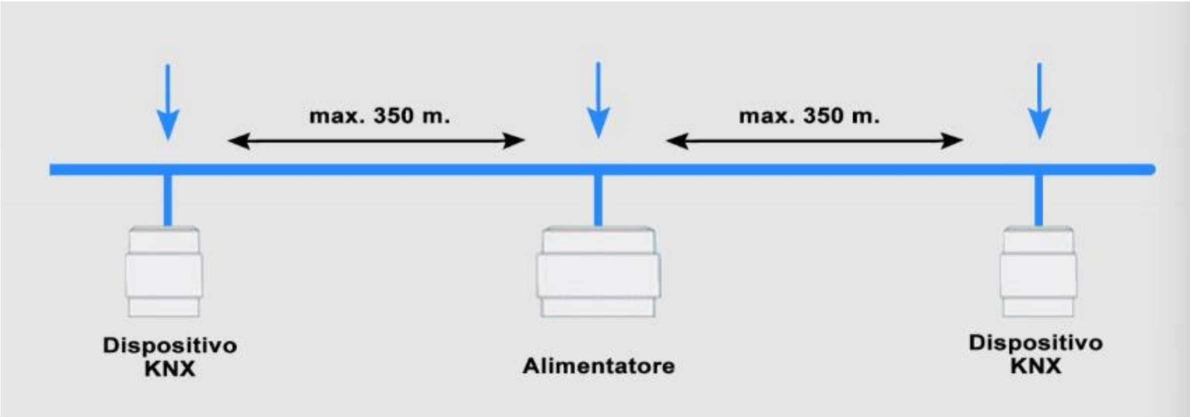


Figure 67: KNX architecture

The sizing of the power supply to be used on each line is based on the concept of associating a maximum consumption of ten milliamperes for each KNX bus device, choosing between three types:

- 160mA for up to 16 devices
- 320mA for up to 32 devices
- 640mA for up to 64 devices.

In the case in question, considering the presence of about 40 devices, a 640 mA power supply will be implanted.

Each device is assigned a unique physical address that can be traced back to the individual component within the architecture. It identifies the name of the device and its location in the system.

Each component communicates through the bus with one or more devices through a data telegram, within which there are sender and recipient addresses and a series of information for operation. For communication between devices, the group address is used, which can have a two-level or three-level structure. It defines the logical connection and the assignment of bus-connected devices to each other.

A fundamental aspect for the final project is the decentralized peer-to-peer architecture, i.e. each device has its own logic that makes it completely autonomous from the other devices, ensuring the system general continuity of service even if a component should fail. [21]

7.3.2 NMEA2000-KNX CONVERTER

As explained above, Garmin's communication protocol is NMEA2000, which implies the presence of a NMEA2000-KNX converter for communication and information exchange between networks.

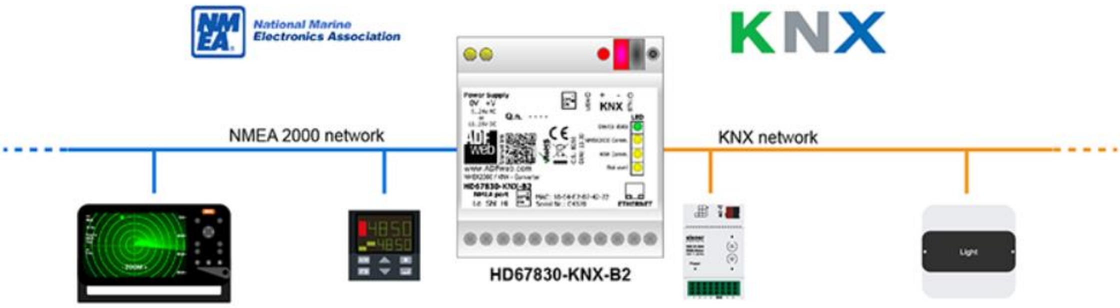


Figure 68: NMEA2000-KNX converter

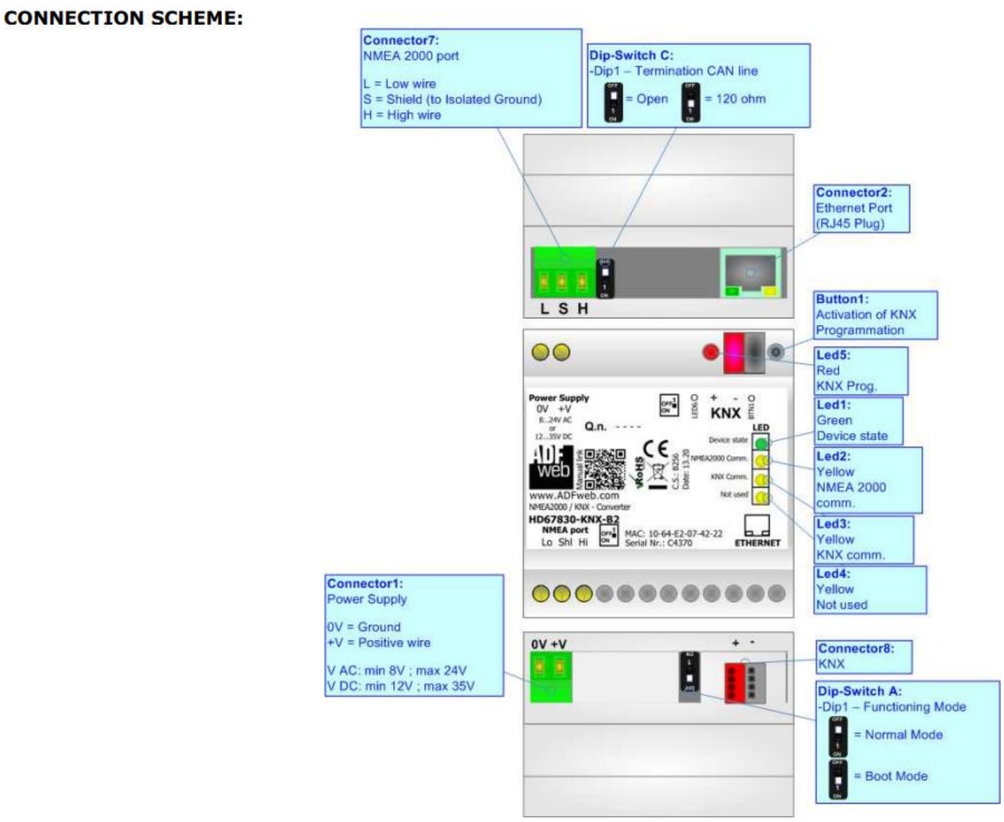


Figure 69: Gateway Connection Diagram

The HD67830 converter has the following features:

- Up to 1440 bytes read and 1440 bytes write;
- Triple insulation between KNX-power, KNX-CAN, power-CAN;
- Bidirectional information between KNX bus and NMEA2000 bus;
- Mountable on 35 mm DIN rail;
- Power input range: 8...24V AC or 12...35V DC;
- Wide temperature range: -40°C / 85°C [-40°F / +185°F];
- The consumption at 24V DC is 3.5 W/VA.

The configuration is done via the Compositor software SW67830 on the PC by defining the parameters of the NMEA2000 line, of KNX, the KNX messages that the converter can accept, the KNX frames that the converter sends through KNX, the map of the KNX bytes that must be written to the NMEA2000 side and the map of the NMEA2000 data that must be written to the KNX messages. [22]

The mechanical dimensions are as follows:

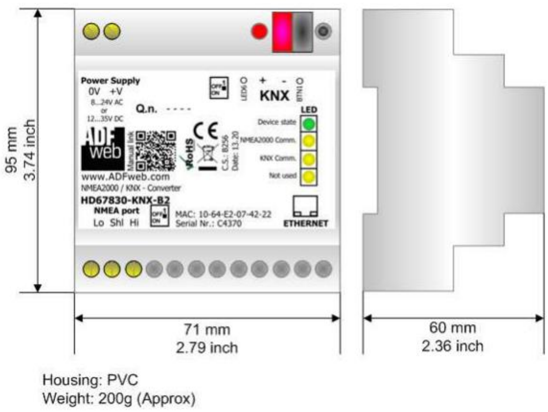


Figure 70: Gateway size

7.3.3 KNX MODULES

VIMAR offers 2-module and 3-module devices, both with and without actuator. In the current case, given the presence of the Garmin CU which represents the brain of the system, the actuator is not necessary, therefore being able to choose the proposal without an actuator.

Given the current requirements, we proceed with the description of the control with four buttons, 2 modules. [20]

Figure 71: KNX module

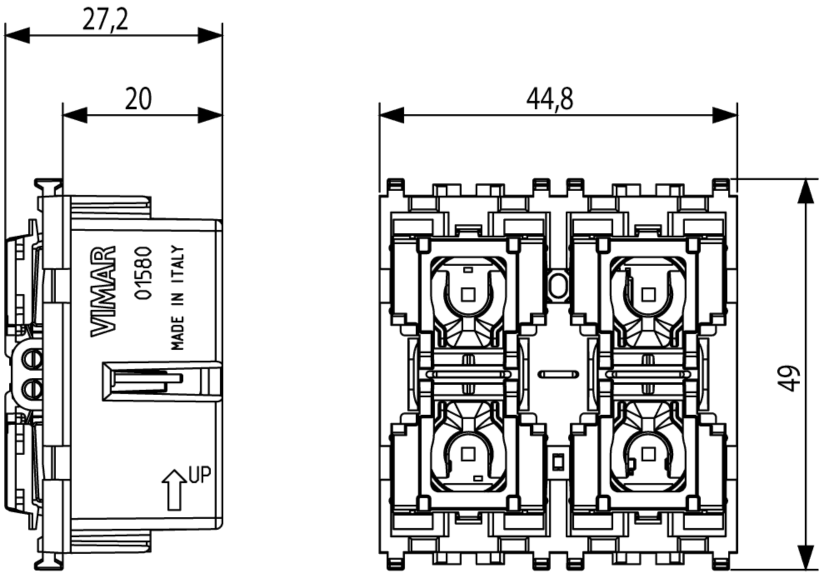


Figure 72: KNX module dimensions

It is a four-button home automation control device, it is a KNX standard, equipped with independent buttons that can be used for ON/OFF commands, light adjustment and there are also RGB LEDs with configurable color.

The methods of use are:

- Functions with independent buttons:
  - Sending ON, OFF, TIMED ON, forcing and toggle commands on both short and long press
  - Switch ON and OFF on the rising and falling edges
  - Scenario recall with short button press, recall of a second scenario or scenario storage on long press
  - Sending one or two values by short or long press of the button
  - Send bit, byte, or 2-byte commands for multiple close presses
  - Dimmer control
- Functions that can be carried out by the buttons with 2 associated channels:
  - Switch ON and OFF
  - Dimmer control

7.4 FINAL COSTS OF THE TWO PROJECTS

Looking at the current project, we understand the positioning and an estimate of the number of both KNX and EnOcean commands.

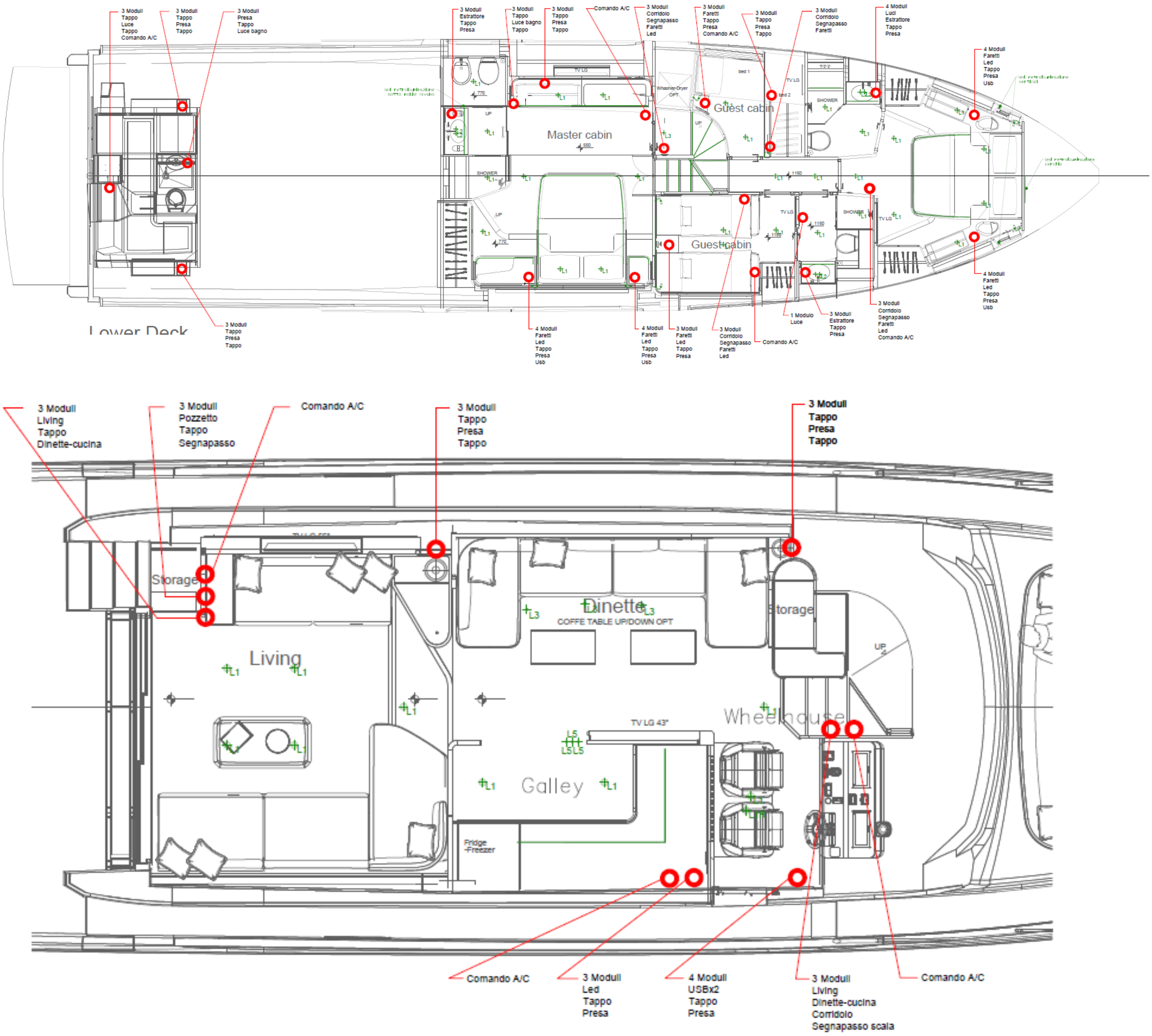


Figure 73: current arrangement of the modules within

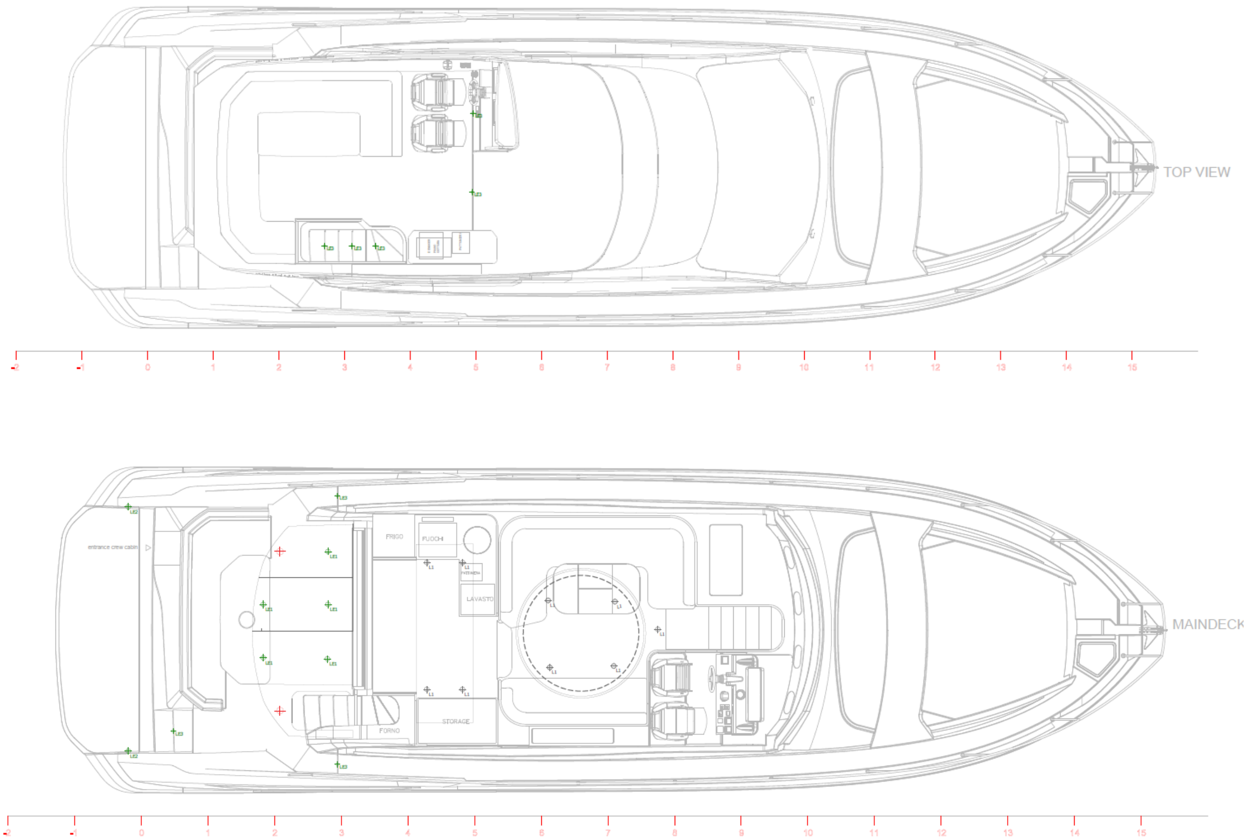


Figure 74: current arrangement of the modules outside

In the current project, the cost of two simple buttons including relays amounts to about 150 euros, the electrical panel and everything that resides inside has a cost of 550 euros to which must be added a labor of 200 euros, for about nine hours of work.

Considering the cost of a single two-module EnOcean control, it amounts to about 75 euros, to which is added the cost of the Garmin CU of about 1100 euros and a labor that turns out to be about half of what is currently needed, considering a cost of 100 euros.

As for the cost of a single two-module KNX control, around 115 euros is taken into account. To this must be added the cost of the Garmin CU, the NMEA2000/KNX converter of about 424 euros, the cost of the cable which amounts to about 157 euros for every 100 meters and the power supply for the KNX network (33 euros).

	EM PROJECT	KNX PROJECT	ENOCEAN PROJECT
MANPOWER	200 euros	100 euros	100 euros
SINGLE MODULE	150 euros	115 euros	75 euros
ELECTRICAL PANEL	550 euros	1100 euros	1100 euros
POWER SUPPLY	/	33 euros	/
CONVERTER NMEA2000	/	424 euros	In case it is not a Garmin CU: 424 euros
TOTAL	900 euros	1770 euros	1275/1700 euros

Table 4: Cost comparison of the three projects

7.5 COMPARISON BETWEEN THE TWO PROPOSED PROJECTS

In both projects, the reduction in weight, space and wiring is remarkable. Suffice it to say that in the current system, only the light box weighs 5 kilos, reaching a weight of 38 kilos considering the wiring.

With the current proposals, the light box would be replaced by a control unit whose weight is ten times smaller and as far as wiring is concerned, in the EnOcean project it would be completely removed, in the KNX project it would be reduced to a simple bus.

One of the strengths of KNX is certainly the interoperability between devices from different manufacturers, allowing them to communicate. At EnOcean this is not guaranteed, as not all CUs, except Garmin, are able to communicate through this standard. A solution to this problem is the NMEA2000/EnOcean converter, to which up to one hundred EnOcean devices can be connected, allowing the integration and read/write of the data of the latter using the NMEA2000 network. The operation is the same as described above for the NMEA2000/KNX converter.

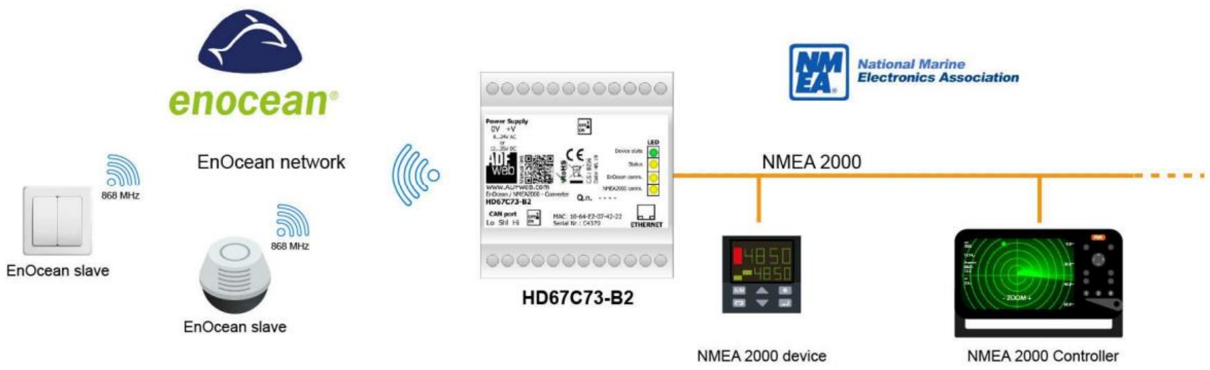


Figure 75: NMEA2000/EnOcean Converter

There is also an important difference in costs, as EnOcean is decidedly cheaper than KNX, but also the reduced choice of EnOcean controls, as there is only the two-module control on the market, as opposed to KNX controls in which there is a wider choice.

A problem that may be present in other boats, but not this one, is interference from EnOcean's radio controls due to the presence of metal plates, concrete or metal walls and therefore the malfunction of the switches.

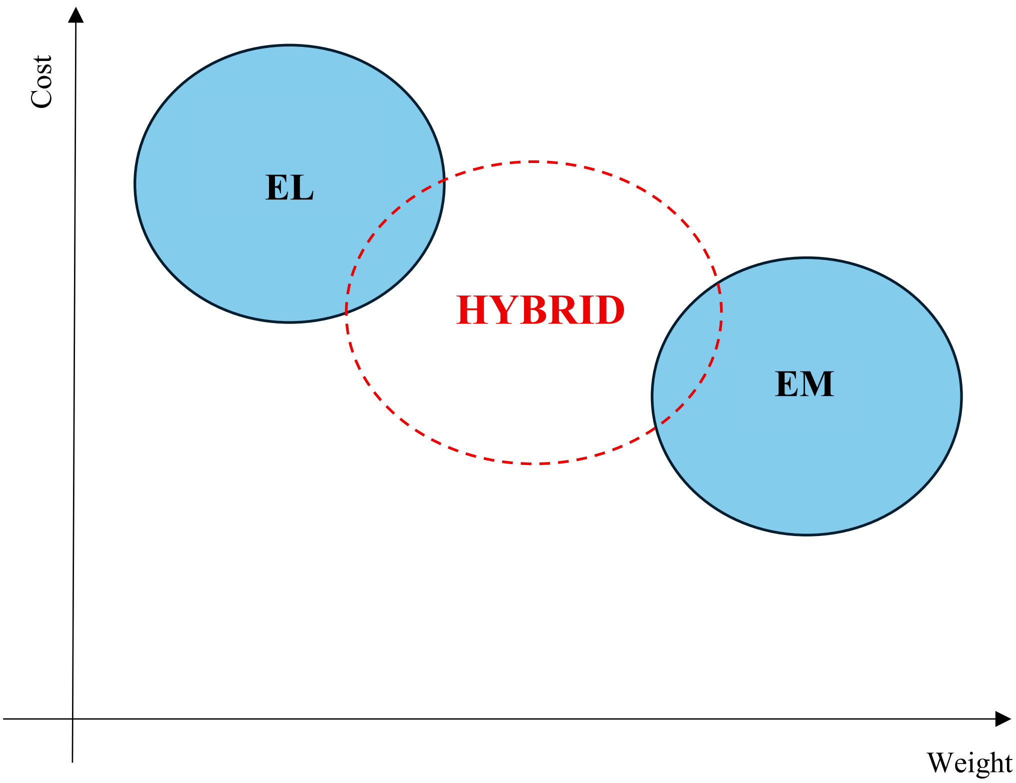


Figure 76: Comparison between ElectroMechanical and Electronic Network, based on costs and weigths

7.6 REGULATORY FRAMEWORK

Considering the regulatory level, it is possible to replace the traditional light panel, including electromechanical devices and fuses for overcurrent control, with EmpirBus, which does not specifically contain fuses, but eFuse.

Standard 13297 has been amended by removing note 1 referring to fuse holders and fuses:

"Note 1 to entry: the fuse is an assembly of all parts forming the protective device. This includes the fuse holder and the fuse-link".

This note referred to the need to use a fuse as a protection device, but with the change in the current legislation, there is no part that restricts the use of traditional fuses or prohibits the use of electronic fuses.

3.5 Overcurrent protection device

Device designed to interrupt the circuit when the current flow exceeds a predetermined value for a predetermined time.

EXAMPLE A fuse (3.29) or circuit breaker

3.29 fuse

Protective device that interrupts the circuit irreversibly when the current flow reaches a specified value for a specific time.

Having removed both references to the *fuse holder* and the *fuse-link*, you can also rely on other devices that achieve the same goal as the traditional fuse.

Also considering the main reference standard for the safety of electrical systems CEI 64-8 which regulates the design, installation and verification of low voltage electrical systems, it is understood that the protective devices must be chosen on the basis of the maximum short-circuit current that can be generated in the electrical system.

A protective device must withstand the destructive energy of short-circuit currents. If a fault current exceeds a level beyond the capacity of the protective device, the device may break and cause damage. Therefore, when choosing the protective device, it is also necessary to consider its degree of interruption, i.e. the ability to maintain its integrity when reacting to fault currents. It is important, therefore, to choose one that can withstand the higher potential short-circuit currents.

This means that MOSFETs can be used as an alternative to fuses if they meet certain requirements, such as voltage, current and power ratings suitable for the circuit in which they are used, current limiting and thermal protection.

As required by IEC 64-8, which states that protective devices must interrupt the short-circuit current within a specific time for the safety of the plant and people, MOSFETs can be designed to interrupt the current within a certain time interval.

In particular, Garmin/EmpirBus circuits are made with the use of Profets, which limit the current actively, thanks to the presence of an integrated short-circuit current limiter, an intrinsic function and operating in parallel with the software-controlled switch function.

The maximum working voltage of the Profet is 48 V, i.e., it is the maximum operating voltage at which the device can work safely. Making a comparison with the traditional ATO fuse, used on board, it can be seen that the latter has a lower maximum voltage than the Profet, precisely 32 V.

PROFET™ +24 V
BTT6100-2ERA

General Product Characteristics

4 General Product Characteristics

4.1 Absolute Maximum Ratings

Table 3 Absolute Maximum Ratings[1)]
T_J = -40°C to 150°C; (unless otherwise specified)

Parameter	Symbol	Values			Unit	Note or Test Condition	Number
		Min.	Typ.	Max.			
Supply Voltages							
Supply voltage	V_S	-0.3	–	48	V	–	P_4.1.1


Blade Fuses

ATOF® Blade Fuses Rated 32V

Developed by Littelfuse for the automotive industry, the ATOF® fuse has become the original equipment circuit protection standard for foreign and domestic automobiles and trucks. Readily identifiable and easily replaced, this fuse can be specified for a variety of low voltage electronic applications.

Specifications	ATOF® (Tin Plated)	ATO Ag (Silver Plated)
Voltage Rating:	32 VDC	32 VDC
Interrupting Rating:	1000A @ 32 VDC	1000A @ 32 VDC
*Recommended Environmental Temperature:	-40°C to +125°C	-40°C to +125°C
Terminals Material:	Tin plated zinc alloy	Silver plated zinc alloy
Housing Material:	PA66 (U.L. 94 Flammability rating – V2)	PA66 (U.L. 94 Flammability rating – V2)
Net Weight Per Fuse:	1.4±5% gr	1.4±5% gr
Complies with:	SAE J1284,ISO 8820-3	SAE J1284,ISO 8820-3
UL Listed:	File AU1410	File AU1410
CSA Certified:	File No. 29862	File No. 29862

ATOF® Blade Fuses

ATO® Ag (Silver plated) Blade Fuses

RoHS

Figure 77: PROFET vs ATOF Comparison

The devices used by Profet are tested according to AEC-Q100, a standard developed by the Automotive Electronics Council (AEC) based on failure mechanisms, for the qualification of stress tests for integrated circuits for automotive applications.

Compared to consumer components, automotive components must operate over a higher temperature range (-40° to 150°) and have a much longer operating life than a component such as a phone.

	Consumer	Automotive
Ambient Temperature Range	0° to 85°C	-40°C to 150°C
Expected Operating Life	2-3 years	10 years+
Acceptable Failure Rates	300 parts per million	Zero
Supply Lifetime	2-3 years	15-20 years

Figure 78: Automotive vs Consumer Comparison

The AEC-Q100 aims to cover failures that occur during the operating life of the component, including random failures and those due to wear; therefore, in the case of Profet, it verifies the resistance of the device to repeated short circuits, in accordance with SAE J1284 and ISO 8820-3 standards, according to which ATO fuses are certified, which provide for a high number of cycles, extreme temperature ranges and a high number of samples.

In particular, the set-up test includes a simulator circuit of a heavy automotive environment, using long cables (20 and 40 meters), chokes and resistors to also realize the real conditions in industrial vehicles and the real impedances of the wiring. These conditions, being much more stressful than those of a traditional car, aim to really verify the robustness and repeatability of the component.

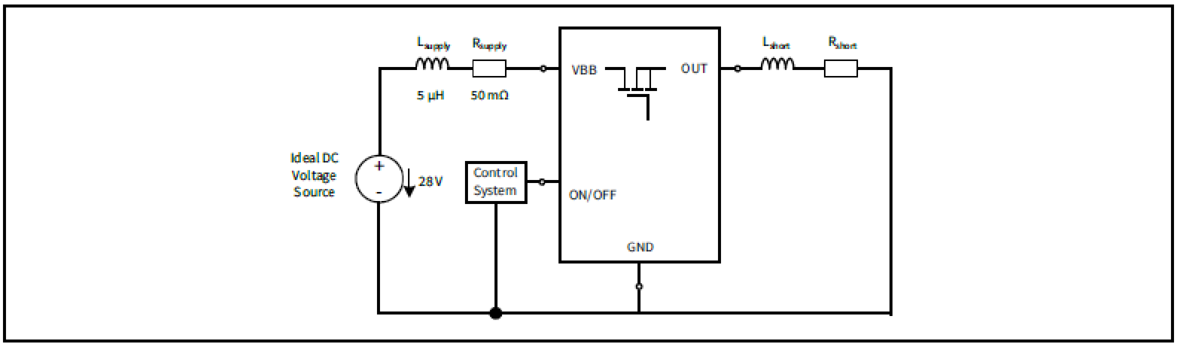


Figure 79: Set-up test

The advantages of electronic fuses, therefore, are: active current limitation, resistance to many tests that simulate short circuits in realistic and severe environments, greater precision in protection and the possibility of recovery after an overload condition, unlike traditional fuses, which trip only once and then must be replaced. [23][24][25][26][27]

8. CONCLUSIONS AND FUTURE WORK

The goal of the work carried out is to be able to make the boat more electronic and less electromechanical, oriented towards the automotive world and also that of home automation.
As for the first Power Monitoring project, what will certainly have to be implemented to have a complete view of consumption is the monitoring of direct current loads.
As far as the lighting system projects are concerned, with both proposed solutions, the goal of significantly reducing the space and weight of the light panel by about ten times is achieved, with the insertion of the Garmin control unit, managing to comply with the regulations.
In particular, with EnOcean there is a significant reduction in manpower as there is not even a bus, but only the positioning of the switches, with a consecutive decrease in costs compared to the KNX project. The latter, in fact, is very close to the home automation world, making the environment intelligent and interoperable.
Future works include the modification and replacement of other electrical panels, both for DC and AC ones, moving more and more towards the world of BUS and home automation, ensuring a decrease in weight, space and manpower.

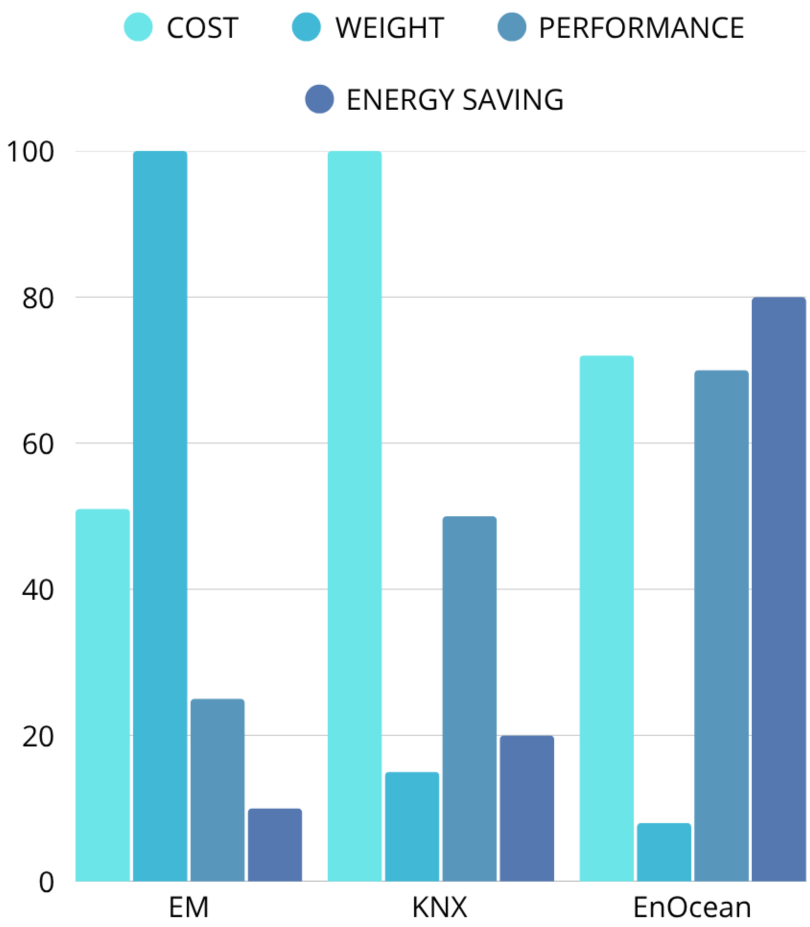


Figure 80: comparison between EM,KNX and EnOcean

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