ESCUELA TÉCNICA SUPERIOR DE NÁUTICA

UNIVERSIDAD DE CANTABRIA

Trabajo Fin de Grado

ESTUDIO TÉCNICO DEL SISTEMA ELÉCTRICO DE UNA GOLETA, INTEGRANDO GENERACIÓN RENOVABLE Y ALMACENAMIENTO ENERGÉTICO.

TECHNICAL STUDY OF THE ELECTRIC SYSTEM OF A SCHOONER, INTEGRATING RENEWABLE GENERATION & ENERGY STORAGE.

Para acceder al Título de Grado en

INGENIERÍA MARINA

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Director: Alberto Pigazo Lopéz

February - 2020

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RESUMEN

En el siguiente proyecto de ingeniería se desarrolla el estudio técnico de la planta generadora eléctrica a bordo de una goleta y la adaptación de la instalación energética al añadir un sistema optimizado de almacenamiento de energía, junto a un sistema de hidrogeneradores.

Al ser considerado un sistema aislado e independiente, la instalación energética a bordo de la goleta debe de cumplir ciertas reglas y condiciones especificas sobre la calidad de la energía eléctrica, al igual que es necesario realizar los cálculos adecuados para asegurar el correcto Balance Eléctrico, para así establecer el diseño más apropiado para la nueva instalación de la energía eléctrica. Creando un sistema optimizado del cual se pueda extraer la mayor eficiencia posible en cada diferente operación a bordo.

Una vez establecida dicha estructura como la base de nuestro sistema energético, se nos abre la oportunidad de modificar y establecer los equipos del sistema de generación y almacenamiento de energía más idóneos para los diferentes tipos de operaciones llevados a bordo, incluyendo la implementación de un sistema de hidrogeneradores, el cual nos aportara energía renovable cuando la goleta este navegando a vela, así mejorando el consumo y el impacto medioambiental de nuestra instalación energética.

ABSTRACT

The following engineering project develops the technical study of the electrical generating plant of a schooner, and the adaptation of its energy installations towards the implementation of an optimise energy storage system, plus a hydrogenation system.

The energy installation on board a schooner, which is considered an isolated and independent system must comply with certain specific rules, and conditions to ensure a minimum upon the quality of the electric energy on board. Also it is necessary to perform the appropriate calculations to ensure the correct Electrical Balance of the system, to be able to establish the most appropriate designs for the new installation of the electric energy system. Creating an optimised system from which it is possible to extract the maximum energy efficiency for every different operation on board.

Once this structure has been established as the base of the energy system, we would have the opportunity to modify and establish the most suitable generating plant, and storage system, which would perfectly adapt to every different operation carried out on board, including the implementation of a hydrogenation system, which would provide renewable energy while sailing, improving its energy consumption and reducing its environmental impact.

PALABRAS CLAVE

Goleta; Buque; Generación eléctrica; almacenamiento eléctrico; banco de baterías; distribución energética; consumo energético; perturbaciones en las red eléctrica; Balance Eléctrico; Hidrogenerador; PODs; red de Corriente Continua; red de Corriente Alterna; Inversores; Energía renovable.

KEYWORDS

Schooner; Vessel; Electricity generation; electricity storage; battery bank; power distribution; energy consumption; disturbances in the electric network; Electric Balance; Hydrogenerator; PODs; DC-Grid; AC-Grid; Inverters; Renewable energy.

1. DESCRIPTIVE MEMORY

1.1. Purpose

The main structure of the electrical installation inside any vessel, specifically on board schooners, have a very similar system to the ones that we can acquire in any electrical networks on land, but at the same time is important to take into account that we are dealing with a complete isolated system, which must be able of self-sustaining itself in all the energy aspects, highlighting of course the electricity as the main energy used on board. The installation must guaranty the proper energy supply in any situation to ensure the security and safety, and the correct operation of all the systems on board.

Any electric network is based on a basic structure, in this cased composed of the loads to supply, the generating plant, the energy storage system, and all the way to the final transmission and distribution of the electricity on board.

The possibility of manipulating the generating plant, and to be able to store energy, gives us the opportunity to accumulate the extra energy created when the generating plant exceeds the consumption loads. When the demand overpasses the generated power, the stored energy, balances the consumption units, until the generated current is increased or the demand is decreased. Along with the storage plant, it makes an increase in the efficiency, gives a better management and it gains in a longer life average of the installation. Creating a more constant and stable system, where the loses and disturbances on the networks are minimised, and the extra energy is accumulated.

Taking these basic pillars into consideration the project is going to develop and estructure the technical study of the complete energy system of a schooner, avoiding and destroying the main electric disturbances. Also creating a project, which is capable of adapting itself to renewable energies, establishing the generating and storage systems into a more green, clean, dynamic and more efficient concept of energy systems.

Introducing a hydrogenation system, which consists of the implementation of two hydrogenerators. The project studies the energy productivity of this devices and how they improve the energy system, combined with a more efficient storage system on board.

Along with the calculations of the Electric Balance of the schooner, comes forward the dimensions and design of the energy generating plant and the energy storage system, subdivided in two main groups of battery banks.

The main generating plant consists of a diesel generator system, to be able to supply all the different demand in every situation. This system is followed by the storage and distribution system formed by the two battery banks, and the battery chargers/inverters, which fulfils the functions of creating a steady constant flow of energy. It also absorbes the remaining energy conceived by the generators, accumulating that spare energy to be used later on without the need of the generators. This systems as well lets the generators work on their most efficient load capacity, because it has constant control and regulation of the energy load which is conceived to the storage system in every demand situation.

The aim of this technical study is to analyse diverse alternatives for renewable generation and energy storage, which can contribute to increase the power system efficiency and reliability. More specifically, hydrogenation and battery systems will be consider and evaluated, both electrically and economically. Considerations about the resulting system reliability, operation and management will be also addressed.

Throughout this exposed purposes and features this technical study contributes to increased the efficiency of the whole energy system on board the schooner. Being able to create hydrogenation energy, and storing it. Decreasing the consumption of the generators, and reducing its working hours. Encompassing everything, the amount of emissions are greatly reduced, the generators maintenance costs are decreased along with the quantity of waists, and last but not least a great economic benefit is achieved.

1.2. Features & General Description of the schooner

The type of vessel in which the project is based on specifically, is of a two masts schooner. A schooner is a sailing boat identified by its rigging configuration, specifically the foremast is slightly shorter than the main mast.

The specific dimension of the schooner in which the technical study is based on are exposed on the following table.

Schooner Dimensions	
Length overall	*50 m*
Beam	*7,5 m*
Draught	*5,5 m*
Gross Tonage	*185 GT*

Table 1. *Schooner dimensions. Table by the author.*

As a sailing vessel the main structure on board is quite simple. Consists of the main engine and a single propeller as the propulsion system, plus its sails, which are composed by four sails. The Main sail, the For-main sail, the Staysail, and the Genova or Yankee, that allow us to absorb the maximum wind energy and transform it through the keel into movement.

On the following page it is exposed a drawing of an over view and a side view of the schooner with its corresponding dimensions, "*Figure 1. Basic Dimensions of the schooner, side view"*.

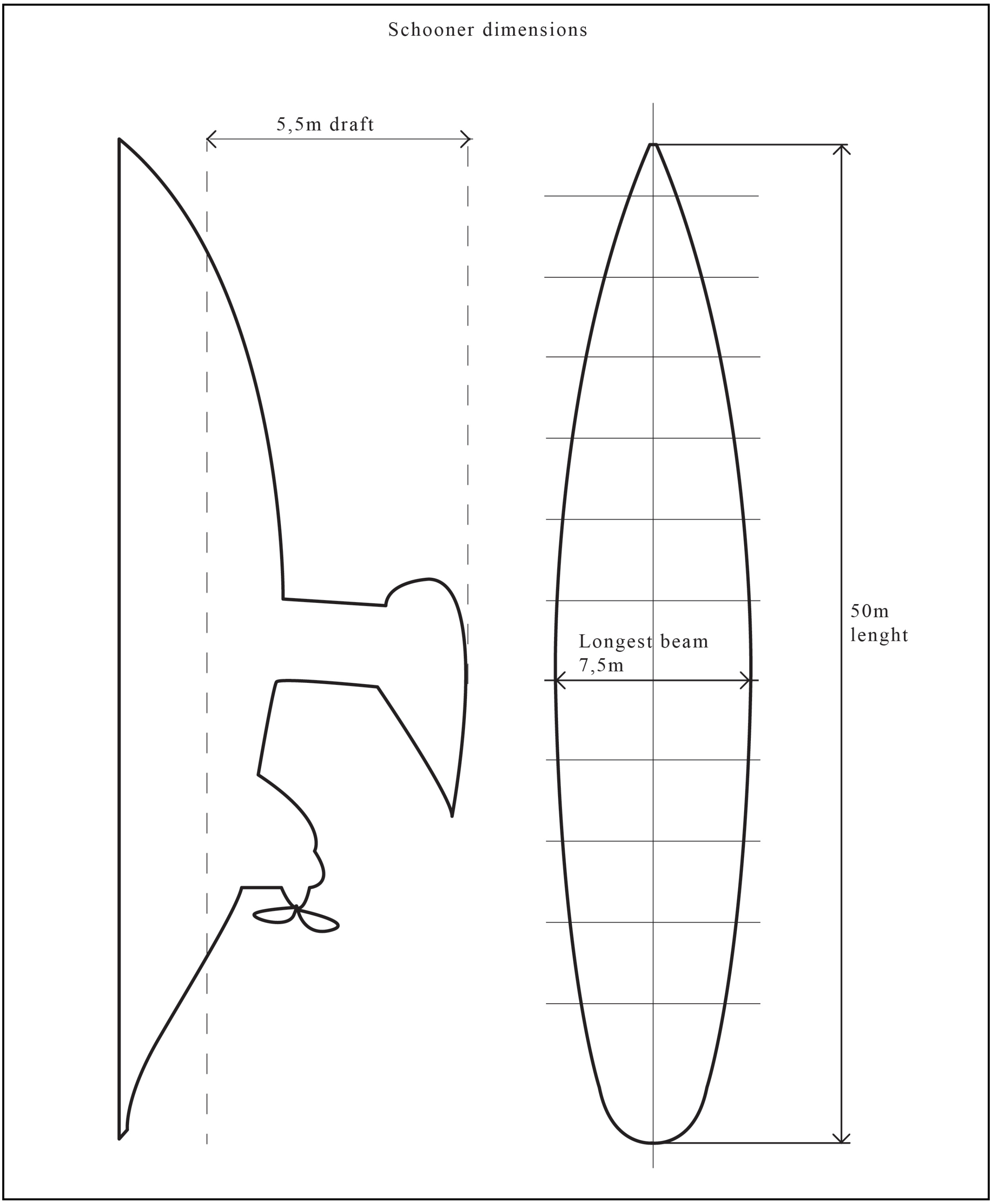

Figure 1. *Basic Dimensions of the schooner, side view. Picture by the author.*

1.3. Features of the power plant

The project is established on a sailing vessel, so it is possible to implement into its generating plant the use of hydrogenerators while sailing, and study the energy efficiency of the installations, plus the environmental and economic benefits.

The schooner is equipped with two mechanical diesel generators located in the engine room, as main electric energy suppliers, which are situated in the stern of the vessel. This generators supply the battery chargers/inverters, from where the electricity is distributed (the electricity is properly delivered through various inversion and transformation processes) throughout the different systems of the installations.

The greatest and heavier loads, which are composed by the windlass, the bow-thruster, the hydraulic pump, water-makers, and air compressors are need to be supplied straight away from the generators. The rest of the demand can be supplied straight from the battery banks and throughout the inverters, but always with the option of being supplied by the generators as well throughout the main busbar. The batteries charging demand is located on an independent energy supply busbar, along with the inverters.

The storage system consists of two battery banks connected in parallel. The energy is distributed and controlled through the charger/inverters, which it works as the brain of the storage and distribution system.

1.4. Generating Power Plant

The schooner starts with the base of a previous established generated power plant ,which needs to supply the different operating loads in every different situation of demand. As exposed on the previous section, the total needed generated power is equivalent to the total final values of the Electric Balances.

To be able to supply this demand, the system is equipped with two Diesel Generators, which have been chosen through the results of a previous Electric Balance, to design the most optimise generating plant. This process is a previous operation to the technical study.

The process which has had acquired the optimise number, and total power of the previous generators setup is equivalent to the maximum total energy generated. Which is composed as the sum of the maximum energy demand operation (total manoeuvre power), the extra daily loads that can be turned on during any situation, plus an extra 5 % security margin added to the final result. The total number of units are the amount of devices which are needed to be supplied, by the generators during every different operation.

The results and specifications of those calculations, and the features of the table of contest are explained, and exposed on the second section of the technical study "*Calculations*".

The final result of those calculations and specifications are the features exposed on the following contest table, "*Table 1. Maximum total generated power needed to supply.* ", which is the base of the generators energy consumption.

Number of Units	Number of Units	Power Installed	Total Power Installed	Utilisation Factor	Total Absorbed Power (P)	Power Factor	Total Reactive Power (Q)	Total Apparent Power (S)
Units	**Total**	**kW**	**kW**	**Ku**	**kW**	**cos(ϕ)**	**kVAr**	**kVA**
Total Manoeuvr Power	89	88,4	96,2	0,856	81,512	0,840	54,470	97,038
Extra Loads	83	26	44,1	0,815	36,43	0,826	22,183	43,725

Number of Units	Number of Units	Power Installed	Total Power Installed	Utilisation Factor	Total Absorbed Power (P)	Power Factor	Total Reactive Power (Q)	Total Apparent Power (S)
Total Manoeuvr + Extra Loads	172	114,4	140,3	0,836	117,942	0,833	76,653	140,763
Total Generated Power (+5% margin)	172	120,12	147,315	0,836	123,8391	0,841	80,486	147,801

Table 1. *Maximum total generated power needed to supply. Table and calculations by the author.*

With the Total Absorbed Power, the fuel rate, plus the total number of running hours of each generator, the total fuel consumption it is obtained.

a) Diesel Generators

The main generator is composed of a Northern Lights M1066A2, 380 V, 50 Hz, with a total output power of 115 kW, at 1500 rpms (revolutions per minute). To be able to supply the greatest operational loads, and most of the extra loads at the same period of time.

The average specific value of the fuel consumption that the technical study and its calculations are going to be based on for the Northern Lights M1066A2 is 35,2 ltr/h (litters per hour). With an exhaust gas volume of 1306 cfm or 37 m3/m.

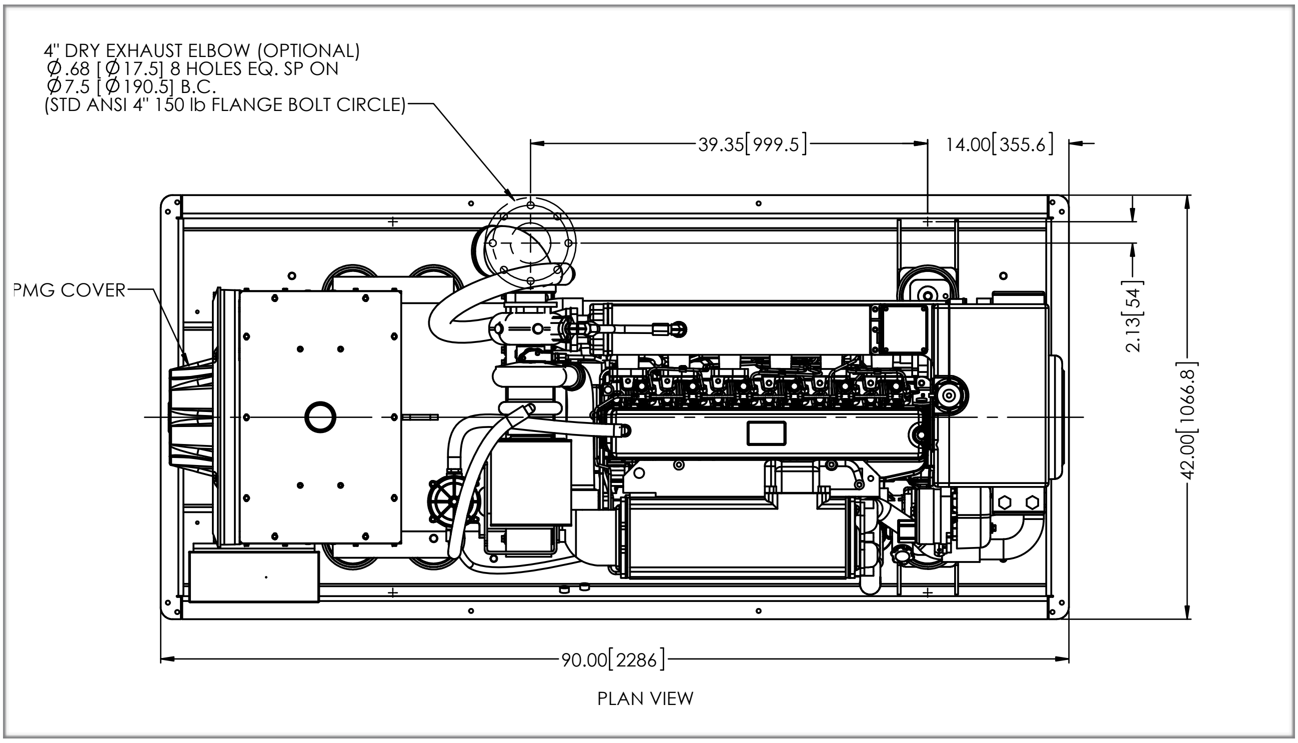

Figure 1. *Northern Lights Diesel Generator, M1066A2. Picture by © Northern Lights, Inc.*

The second generator is the Northern Lights M1066T, 380 V, 50 Hz, with a total output power of 80 kW suitable to operate and maintain the greatest operational loads, which are accomplished during the “Manoeuvring operations”.

The average specific value of the fuel consumption that the technical study and its calculations are going to be based on for the Northern Lights M1066T is 24 ltr/h. With an exhaust gas volume of 600 cfm or 17 m3/m.

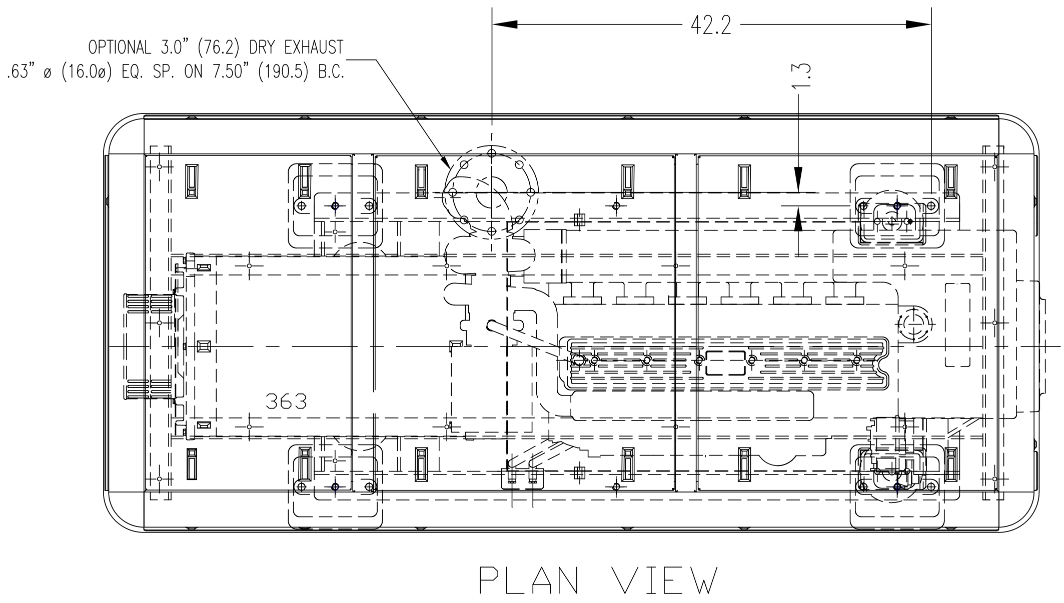

Figure 2. *Northern Lights Generator, M1066T. Picture by © Northern Lights, Inc.*

Both generators are suited to work in parallel, as it is specified on its manuals. Thanks to that we can play with the different loads, and the amount of generators to achieve the most efficient energy generation for every different operation. The energy generated supplies the AC busbar or independently the batteries charger busbar.

The main features of our three-phase generators, which have a power factor of 0,8 are exposed in the following contest tables. The most efficient operating rate is achieved when the generators are operating at an 80 % supply load.

GENERATOR SPECIFICATIONS						
Type	**Frequency**	**Voltage**	**Number of Revolutions Per Minute**	**Total Generated Power**	**80 % Generated Power**	**Total Synchronised Power**
Units	**Hz**	**V**	**rpms**	**kW**	**kW**	**kW**
M1066T	50	380	1500	80	64	156
M1066A2	50	380	1500	115	92	156

Table 2. *General Specifications of the M1066 A2 & T Models. Information by © Northern Lights, Inc.*

Features of the Generators						
Type	**Number Of Cylinders**	**Bore**	**Stroke**	**Displacement**	**Fuel System**	**Aspiration**
Units	**In line**	**mm**	**mm**	**Ltr**	**Type**	**Type**
M1066A2	6	106	127	6,8	Electronics	Turbo & Aftercooled
M1066T	6	106	127	6,8	Electronics	Turbocharg ed

Table 3. *General Features of the M1066 A2 & T Models. Information by © Northern Lights, Inc.*

Dimensions	Length	Width	Height	Weight
	mm	**mm**	**mm**	**Kg**
	2286	1067	1054	1098

Table 4. *General dimensions of the M1066 A2 & T Models. Information by © Northern Lights, Inc.*

Bothe Generators complies with the approval of Classification Standards ABS and the relevant requirements of Lloyd's Register for Marine Generators applications.

1.5. Electric Balance on board

The first stage to obtain the electric balance would be to calculate the Total Absorbed Power by each device in the different modes of operation. That result gives the total power needed to be supplied from each different energy generator, as well as the function state of use of the battery systems, and the hydrogenation system (energy systems). To be able to ensure the correct operation of every different electric device, in each different load situation. This process and calculations gives the total consumption of the suppliers on board, and the most energy demanding operations are established.

These goal is achieved by completing the following steps and concepts:

a) Recognise which electric receptors becomes active in each different situation.
b) Measure the operation consumption of each device for each load state.
c) Establish the greatest consumption operation.
d) Establish the appropriate nominal power of each generator in the main operations.
e) Establish the number of generators in function for each situation.
f) Identify the load distribution for each generator for every posible situation.
g) Establish in which operations the storage system is supplying energy or storing it.
h) Establish the amount of energy created by the hydrogenation system and its distribution.

Taking into account those steps, the electric balance consist of the electricity demand analysis of the power plant, and the load state research of all the electric devices on board for each different operation. Acquiring the energy generation, consumption, and the amount of energy stored for the different main operations on board, achieved by the generators, the storage system, and the hydrogenation system.

All the devices which creates the network must been taken in account, together with all their features.

With the Utilisation Factor (Ku), the Absorbed Power (P) is available. It is the addition of the Power Installed alongside the Utilisation Factor. The Reactive Power (Q) is the measure given to the power and the energy applied by the induction fields to excite the electric motors, so is important to take it into account, as well as the calculation of the Apparent Power (S).

The proper explanation and analysis of the Electric Balance is developed further more in the second section of the project, “*Calculations”*.

a) Aspects of the electric loads to supply

The electric devices first of all must be divided into two main different supply groups, one for Alternative Current (AC), and another one for the Direct Current (DC), to achieve the correct electric balance, and later on the final value must be added together. All the demand independently if they are AC or DC can be supplied straight away from the storage system and through the inverters, which is constantly monitoring and establishing the most efficient energy flow throughout the installation. With the exception of the greatest AC loads that need to be supplied straightaway from at least one of the diesel generators.

Another aspect to take into account would be their steady-state and transient characteristics, which pulls this aspects apart into two other groups, lineal loads or no lineal.

The DC loads go through a filter of performance of the power to supply, and it is highlighted by the load transient response, the load regulation and the current limit. The main dominant operation for an electric Direct Current Load is constant current, constant resistance, constant power, and the voltage which is imposed by the energy supplier and the interaction with the different loads and the system.

b) Classification of electrical loads to supply on board. Electric balance

First of all it is important to take into account the features and components that creates the estructure of the schooner, and the proper equipment that forms the electrical installation. Including the measures and dimensions, all the way to the electric balance of the loads to supply, towards the generation and storage system.

Once the main features of the schooner have been established, with the corresponding electric balance, the development of the generating and storage plant can be started with its appropriate calculations.

The energy demand and the power of the variating loads must always be supplied by the generators with an appropriate margin over the energy to supply.

The final results, tables and processes of the different established Electric Balances for the installation of the schooner of every different operation system are exposed on the second section, “Calculations”, and the third section, “Project Specifications & Blueprints”.

1.6. International Rules of the Electrical Energy on Board

The International Electrotechnical Commission (IEC), the Institute of Electrical and Electronics Engineers (IEEE), together with the International Organisation for Standardisation (ISO), as well as the SOLAS are a few organisations, which normalise and establish the rules inside the electrical fields, electronic fields and also into related technologies of the same range.

The regulations and standards, from which this project is established, are exposed in this section.

IEEE 45-2017. The IEEE Recommended Practice for Electrical Installations on Shipboard, "*establish the minimally acceptable guidelines for the design, selection, and installation of systems and equipment aboard marine vessels applying electrical apparatus for power, propulsion, steering, automation, navigation, lighting, and communication. These recommendations describe present-day acceptable electrical engineering methods and practices".*

The purpose of this standard "is to provide a consensus of recommended practices in the unique field of marine electrical engineering as applied specifically to ships, shipboard systems, and equipment".

Inside the section 4, of the IEEE 45-2017, all the power system characteristics are stablished. The main characteristics which must be taken into account are the following ones.

The standard voltages recognised and established by IEEE 45-2017, it is exposed in the following Table 1" *Standard Voltages by IEEE 45-2017, section 4.2*".

Standard	AC	DC
Units	**V**	**V**
Power utilisation	115-200-220-230-350-440	115 and 230
Power generation	120-208-220-240-380-450	120 and 240

Table 1. *Standard Voltages by IEEE 45-2017, section 4.2.*

The selection of the voltage and system type is established in the standard IEEE 45-2017, section 4.4, and for the schooner and its dimensions the standard specifies that for vessels with power apparatus greater than 100 kW "*For large vessels of a size and type that requires dual-voltage system (two systems isolated b y transformers operating at different voltages), first consideration should be given to 450-V, 480-V, 600-V, or 690-V generation with power utilisation at 440 V, or 460 V, 575 V, or 660 V, respectively, and lighting distribution at 120-V or 230-V three-phase, three-wire or 120/208-V, three-phase, four-wire*".

The AC power system characteristic are established on the section 4.5 of the IEEE 45. During operating conditions the power distribution system should maintain the following characteristics.

Characteristics (Frequency)	
a) Nominal frequency	50/60 Hz
b) Frequency tolerance	3 %
c) Frequency modulation	0,5 %
d) Frequency transient: **1) Tolerance** **2) Recovery time**	 4 % 2 s
e) The worst-case frequency excursion from nominal frequency resulting from item b), item c), and item d) 1) combined, expect under emergency conditions	5 1/2 %

Table 2. *AC Power characteristics. Table by IEEE 45, section 4.5 "AC power system characteristics".*

IEEE Std. 45-2017, states in section 5 that "*Power system design*", it is an important section to take into account for the elaboration of the project. Specifically in section 5.1 "*General*", which is quoted as follow, and exposed as seen in the picture of "*Figure 1, Typical integrated electrical plant configuration from a passenger vessel*".

" For the purposes of this document, distribution will include all electrical devices after the switchboard load terminals and before the electrical load power terminal. A distribution system includes, but is not limited to, all power transformers, automatic bus transfer switches, motor control centers, load centers, distribution panels, controllers, feeders, and branch circuits. The distribution system does not include generators, switchboards, and electrical loads "

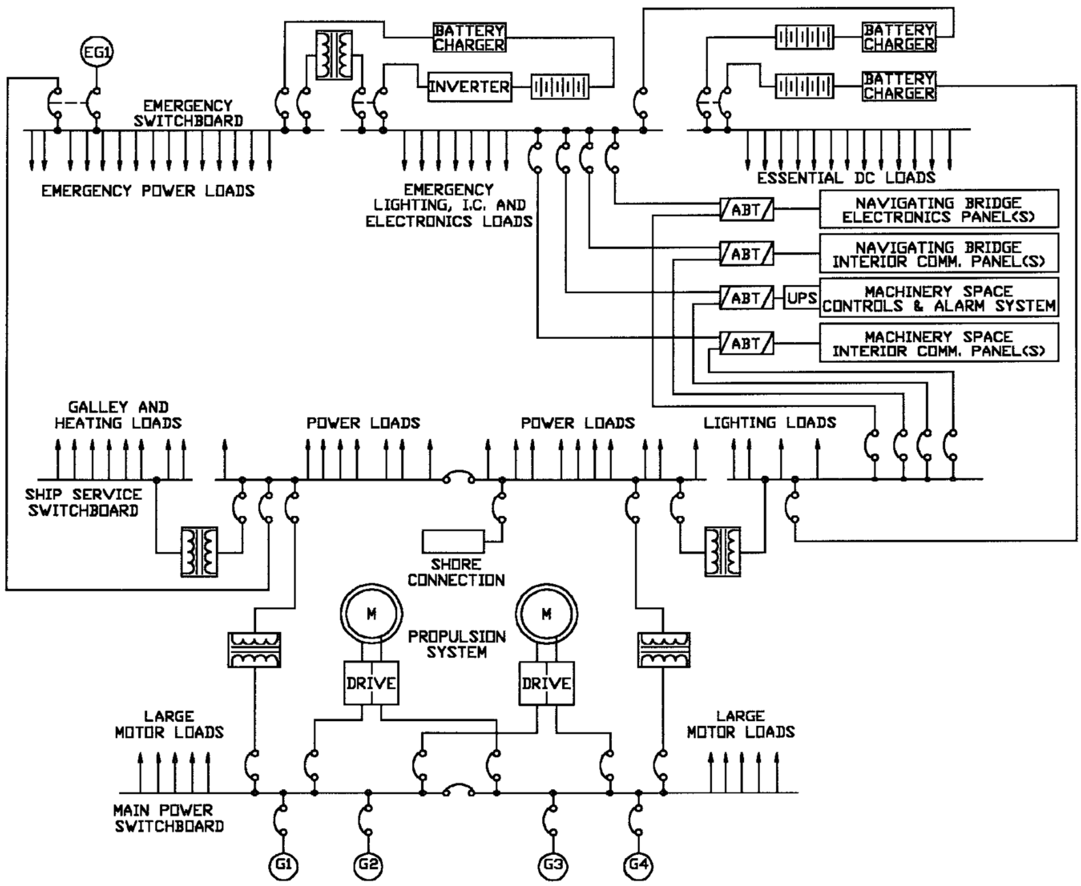

Figure 1*. Typical integrated electrical plant configuration from a passenger vessel. Picture from IEEE Std 45-2002, section 5.1 General.*

The section 5.2 “*Circuit Elements*”, it is defined as “ *All normal current-carrying elements of electrical power supply circuits should be specifically intended for that purpose only. Ship structure should not be used as a normal current-carrying conductor for the electrical power supply distribution system*”

The “System protection”, takes consideration of the short-circuit protection and good care selecting the various protective devices, that can ensure the correct interrupting capacity and coordination despite their location on board. This is developed in the section 5.9, which is defined as according to the following quotes.

“Feeder and branch circuits for lighting, heating, and ship service power distribution should each have an ungrounded conductor protected by a circuit breaker or fuse of suitable interrupting capacity”

“Protective devices should be applied so that single-phase operation of any three-phase connected ac motor will be precluded. Protective devices should not be used beyond their interrupting capacity”

The Electric power generation by the IEEE Std 45-2017, exposes that "*Electric power generating systems discussed in Clause 7 consists of one or more generator sets. These recommendations include both sound engineering practices and special considerations for safe and reliable operation in marine applications*"

The sizing of the electric power generators is developed inside the section "Prime movers", specifically the section 7.3.1 "*Sizing*".

"It is recommended that prime movers for generator applications have a minimum continuous shaft horsepower (HP) output according to Equation"

$$HPmin = (100 * DesignkWLoad)/(0{,}746 * GeneratorEfficiency)$$

***Equation 1**. HP min. Equation given by IEEE Std 45-2017 section 7.3.1.*

According to the section 7.4 "*Generators", in the first subsection "General", states that:*

"Electric generators should be designed to perform in accordance with NEMA, MG-1, ANSI C50, or IEC 60034. Generators are normally three-phase, except for small systems that serve only single-phase loads".

Section *13.2 "Ac and dc motors- general" ,* indicates the rules and specifications required for the electric motors (PODs included) "*Electric motors are selected for the load requirement and the voltage, phase, and frequency of the power system. The motor design and estructure should be suitable for both the load application and environmental conditions* ".

"*Motors should be designed and constructed to meet NEMA or IEC dimensional and performance standards*"

Section 22, "*Storage Batteries*", establishes the conditions that must be met by the storage system. As it says in the following quote, from the point 22.5 "*Selection and assembly*".

"*Batteries should be selected to withstand all conditions that may be encountered in the shipboard application*"

Section 31.13.2 "*POD unit*", develops the standard features and specifications of the POD system to be able to installed on board.

"The requirement of the IEC standards, specifically the shipbuilding related standards of the serial IEC 60092, have to be fulfilled"

The point 1 "Generators and motors" from section 31.15 "Tests" indicates "*Generators and motors should successfully pass the following tests at the place of manufacture. The following tests should be conducted in accordance with IEC60034 or IEEE Std 112-1996, IEEE Std 115-1995, or ANSI/ NEMA MG 1-1998, as applicable:*"

"a) Temperature rise under rated load or rated current conditions"

"b) Dielectric strength of insulation"

"c) Overload capacity, as specified"

"d) Cold resistance of all circuits"

"e) Mechanical balance (special considerations should be made on differences in stiffness of test bed and the actual installation)"

The SOLAS - International Convention for the Safety of Life at Sea Chapter II-1 - "*Construction - Structure, subdivision and stability, machinery and electrical installations*". From which we highlight the "*Regulation 41. Main source of electrical power and lighting systems*", which are exposed in the following quotes.

"1.1. A main source of electrical power of sufficient capacity to supply all those services mentioned in regulation 40.1.1 shall be provided. This main source of electrical power shall consist of at least two generating sets. "

"1.2. The capacity of these generating sets shall be such that in the event of any one generating set being stopped it will still be possible to supply those services necessary to provide normal operational conditions of propulsion and safety. Minimum comfortable conditions of habitability shall also be ensured which include at least adequate services for cooking, heating, domestic refrigeration, mechanical ventilation, sanitary and fresh water."

"1.3. The arrangements of the ship's main source of electrical power shall be such that the services referred to in regulation 40.1.1 can be maintained regardless of the speed and direction of rotation of the propulsion machinery of shafting."

"1.4. In addition, the generating sets shall be such as to ensure that with any one generator or its primary source of power out of operation, the remaining generating sets shall be capable of providing the electrical service necessary to start the main propulsion plant from dead ship condition. The emergency source of electrical power may be used for the peruse of starting from dead ship conditions. The emergency source of electrical power may be used for the purpose of starting from dead ship condition if its capability either alone or combined with that of any other source of electrical power is sufficient to provide at the same time those services required to be supplied by regulations 42.2.1 to 42.2.3 or 43.2.1 to 43.2.4."

"1.5. Where transformers constitute an essential part of the electrical supply system required by this paragraph, the system should be so arrange as to ensure the same continuity of the supply as is stated in this paragraph."

"2.1. A main electric lighting system, which shall provide illumination throughout those parts of the ship normally accessible to, and used by passengers or crew shall be supplied from the main source of electrical power."

"2.2. The arrangement of the main electric lighting system shall be such that a fire to other casualty in spaces containing the main source of electrical power, associated transforming equipment, if any, the main switchboard and the main lighting switchboard, will not render the emergency electric lighting system required by regulations 42.2.1 and 42.2.2 and 43.2.3 inoperative."

"2.3. The arrangement of the emergency electric lighting system shall be such that a fire or other casualty in space containing the emergency source of electrical power, associated transforming equipment, if any, the emergency switchboard and the emergency lighting switchboard will not render the main electric lighting system required by the regulation inoperative."

"3. The main switchboard shall be so placed relative to one main generating station that, as far as is practicable, the integrity of the normal electrical supply may be affected only by a fire or other casualty in one space. An environmental enclosure for the main switchboard, such as may be provided by a machinery control room situated with the main boundaries of the space, is not to be considered as separating the switchboard from the generator."

"6. In passenger ships contracted on or after July 2010, supplementary lighting shall be provided in all cabins to clearly indicate the exit, so that occupants will be able to find their way to the doors. Such lighting, which main be connected to an emergency source of power or have a self-contained source of electrical power in each cabin, shall automatically illuminate when power to the normal cabin lighting is lost and remain own for as minimum of 30 minutes."

The quality of the electric energy is established by the standard IEC 61000-4-30, which defines the measurement method, the accuracy and the aggregation of time to the veracity of the power quality parameters divided into three different performance classes, to obtain a repeatable and comparable results. In addition, IEC 62586-1 defines the EMC, safety and environmental requirements for power quality analysers in different installation conditions and IEC 62586-2 defines the test and uncertainty requirement to comply with IEC 61000-4-30 A class.

The parameters of the possibles disturbances that are introduced and defined by the standard IEC 61000-4-30 are:

- Power frequency
- Magnitude of the supply voltage
- The Flicker* (*developed by IEC 61000-4-15)*
- Supply / surge drops
- Voltage interruptions
- Voltage imbalance
- Voltage harmonics** (*by reference to IEC 61000-4-7*)
- Voltage interharmonics** *(by reference to IEC 61000-4-7)*
- Deviation below and over-deviation

**The Flicker (developed by IEC 61000-4-15) "Electromagnetic compatibility (EMC) – Part 4-15: Testing and measurement techniques – Flickermeter – Functional and design specifications"*

***Voltage harmonics & interharmonics (by reference to IEC 61000-4-7) "Electromagnetic compatibility (EMC) Part 4-7: Testing and measurement techniques – General guide on harmonics and interharmonics measurements and instrumentation, for power supply systems and equipment connected thereto".*

In the 3rd addition, the following parameters were introduced:

-Rapid voltage changes
-Magnitude of the current
-Current imbalance
-Current harmonics (*by reference to IEC 61000-4-7*)
-Current interharmonics (*by reference to IEC 61000-4-7*)

"*The standard is updated periodically as the industry evolves and new measurement scenarios are discovered or required. Since its introduction in 2003, the standard has been updated several times and is currently in its 3rd edition*"

The standards that specifies with the electric energy supplied on board ships, which take into account the differences of the installations are:

- The I*EC 60092-101:2018 & ETAP IEC 60092.*

"Provide a complete current capacity sizing calculations for power cables concerning electrical installations in seagoing ships and fixed or mobile offshore units for cables with voltages up to and including 15 kV."

- Electrical installations in ships - *Part 101: Definitions and general requirements.*

"The EC 60092-101:2018 is applicable to electrical installations for use in ships. The 60092 series form a code of practical interpretation and amplification of the requirements of the International Convention for the Safety of Life at Sea, a guide for future regulations which may be prepared and a statement of practice for use by ship-owners, shipbuilders and appropriate organisations."

The method of measurement of the frequency in the electric network on board needs to apply a different mechanism than the ones used for the electrical installations on land, like the standards IEC. Thats why Societies of classification like Lloyds Register of Shipping (LRS), and Det Norske Veritas (DNV) have also created their own regulation and legislation in the different problems and disturbances of the electric quality on board, specifying the proper electrical characteristics of the installation, including the frequency measurements. Also the International Association of Classification Societies (IACS) has defined the maximum total harmonic distortion (THC), as a maximum of the 8 %.

Parameters	Limit LRS	Limit DNV
Frequency:		
A) Frequency deviation (permanent)	5 %	5 %
B) Temporal frequency deviations	10 %	10 %
C) Temporal frequency deviations recovery time	Maximum 5 s	—
Voltage:		
A) Voltage deviation (permanent)	+ 6 % - 10 %	2.5 %
B) Slow temporal voltage deviation (load variation)	+ 20 % - 15 %	+ 20 % - 15 %
C) Time of recovery of the temporal voltage deviation	1.5 s	—
Voltage wave form distortion:		
A) Total maximum harmonic distortion, THD	8 %	5 %
B) Maximum for an individual harmonic	1.5 %	—

Tabla 1. *General characteristic according to the regulations of LRS and DNV. Information from LRS & DNV.*

1.7. Distribution of the Electric Energy

a) Quality of the Energy on Board

The electric energy, while created as a tree-phase sinusoidal wave is define by four different parameters: form, frequency, amplitude and symmetry.

The quality of these waves is a combination of the quality of the voltage of the wave supplied and the continuity of the supplied current generated, which any deviation of any of these two parameters would create a disturbance on the ideal values, affecting the quality of the energy.

The alterations and disturbances are created in the same electrical installation by the simple fact of using them. It is the result of the connection and disconnection of different loads. Always taking into account that one of the natural properties of the electricity is that it deteriorates with the use.

b) Disturbances in the electric network.

Electric variations, and furthermore disruptions are formed in different ways; frequency variation, voltage variation, voltage fluctuation and flicker. Including the impact of over voltage, along with the formation of brief breakdowns and voltage gaps.

As well as the distortion on the form of the voltage and current wave, transitory disturbances and the disproportion or imbalance of the voltage, without forgetting the formation of harmonics.

1. Frequency variation

The frequency variation is the consequence of the difference between the energy generated and the demand to supply (the load variation). This frequency is directly proportional to the alternator or generator speed with certain tolerance, being the nominal value 50 or 60 Hz, depending on the installation.
A decent constant balance is achieve with the speed regulators, which detects the changes on the load and regulates the amount of mechanical energy that would be required. To get a quicker reaction always the generated capacity is gently greater that the load to supply.

2. Voltage variation

Sudden voltage variation caused by the constant connection and disconnection of different loads on the demand to supply forms disturbances on the nominal voltage, which must remain within the established values.

The voltage drops in the electric system usually are not a direct hazard on the devices connected to the electric installation, but it can cause failure on the devices, which they won't have enough energy to function properly or in the desired function state.

The over voltage, contradictory to the voltage drops creates an increase in the temperature of the device, that if it exceeds its temperature limit would eventually cause the breakdown of the apparatus.

3. Voltage Fluctuation and Flicker

The fluctuations on the electric network is the consequence of periodic variations or random changes in the voltage effective value during an unspecified period of time.
These voltages variations can last from various milliseconds, all the way to a period of 10 seconds, with an amplitud not greater or lower than the 10 % of the nominal value.

One of the main disturbances on the electric network, which can even be visually appreciated in the light luminosity, cause by the development of the voltage fluctuation, creating the effect called Flicker. It is an annoying change in luminosity appreciated by the visual perception.
The Flicker depends on the frequency, amplitude and the period of voltage variation.

The voltage fluctuation is rarely created through the generation process, however are conceive by the receivers, which don't have a constant load and generates greater changes on the demand to supply, like welding machines, heating resistors, the started of electric motors, impulse controlled loads, etc.

The Flicker is not really a hazard effect in the devices of the installation, but still has its measurement criteria. The Flickermeter is the measure instrument used to evaluate the Perceptivity.

4. Brief breakdowns and voltage gaps

A voltage gap is define as a sharp decline of the supply voltage with values comprised between the 90 % and the 5 % of the voltage nominal value, followed by a voltage instant recovery during a short period of time. A voltage variation which won't exceed a decline of at least the 90 % of the nominal value, won't be consider a voltage gap.

These voltage gaps are define by two main parameters; the so called residual voltage or depth, and the period.

The residual voltage is the lowest value measured during the period of a voltage gap. Then the depth is the difference between the nominal voltage and the residual voltage.

The period is the duration from the start to the end of the voltage gap, and by agreement it must last from 10 milliseconds to a maximum of a minute.

When the supplied voltage is decreased to a 1 % of the nominal voltage, we are talking about brief voltage breakdowns. These brief interruptions are consider of short duration when its period is inferior to three minutes, and they are recognise as long duration when they exceed that period of time.

These disturbances are the cause of failures in side distribution network, and can be caused by deficiency on the isolation, falses manoeuvres, loads with vast variables, etc.
The consequences of these types of failures can be the flaw or fault of the devices connected to the electric network.

The apparatus more sensitive against the voltage disruption are the electronic devices as computers, PLCs, relays and contactors, electric motors and their governor systems, illumination systems, etc. To be able to measure the sensibility of each device the Computer Business Manufacture Association (CBEMA) designed a tolerance curve. This curve shows the admissible magnitud of under voltage and over voltage of each apparatus.

5. Distortion of the form of the voltage and current wave. Formation of harmonics

The harmonics are alterations in the form of the voltage and current wave inside an electric power system. They are components of the frequency, which values are multiples of the fundamental frequency of the network.

These disorder is caused by the connexion and disconnection of none linear loads. These none linear loads absorb none linear currents, which when they travel through the impedances of the system create none linear under voltage in the system deforming the form of the wave of the voltage supplied.

Industrial devices like rectifiers, inverters, transformers, and most of the devices with a magnetic core, etc. provoke the harmonics inside each electric system.

The main consequences of the harmonics is the heating inside the electric motors plus the additional losses, which decreases the life time of the apparatus. Also failures on then isolation, heating up capacitors and fuses (even to their breaking point), and the malfunction of relays.

The interharmonics are defined by the Institute of Electrical and Electronics Engineers (IEEE), as:

"A frequency component of a periodic quantity that is not an integer multiple of the frequency at which the supply system is operating (e.g., 50 Hz or 60 Hz)."

May cause issues with inductive coils and electromagnetic fields, creating weird noises in the coils of stators and audio systems. Although the most dramatic disturbance would be the Flicker, affecting the illumination systems.

6. Disproportion or voltage imbalance between phases

The fluctuation or disequilibrium of the voltage-phase, which disturbs the three-phase electric system is precipitated by asymmetric three-phase loads, or by the connection of mono-phase loads with different current magnitud in each phase.

The National Electrical Manufacturers Association (NEMA), describes the voltage unbalance between phases as;

"The maximum deviation over the average value phase to phase, respect, the average value of the three voltage, phase to phase."

Disturbs the induction three-phase motors and electronic converters, increasing the temperature and the losses of the devices. For these reasons the NEMA created a limit of the 5 % in the "derating" of each device (voltage gap between phase to phase not greater than 5 %).

These three-phase voltage deviation is not very common on low voltage systems, but on industrial scale is a more familiar disturbance, which must be take in to account.

1.8. Energy Storage System

Nowadays the patterns for producing and storing electric energy are constantly evolving and new methods are continually being discovered. The progression and transformation of the energy generation is increasing the intricacy of the installation designs, increasing the efficiency of the installations, and throughout that decreasing the consumption of the diesel generators.

It is essential to create a proper Electric Balance of the loads to supply, acquiring the correct energy storage values to establish the Battery Banks, where the extra energy created by the diesel generators is stored (so they are constantly running on the their most efficient load reate, which is 80 % load), and the energy created through the hydrogenation system is stored. Being able to use that energy later on into the lower demand operations, without the need of using the generators.

While designing and creating a battery storage, and battery power plant is essential to analyse the battery bank behaviour on their different states of operation, during charging or throughout the supplying time of the loads demand through the inverters (discharging). Aiming to arrange the most optimise and acquiring the greatest efficiency for the battery system.

a) Loads to Supply through the storage system

First of all is necessary to make a proper selection of the loads to supply and the total amount of energy demand, to be able to install the proper amount of batteries and charger/ inverters for the system. The storage system must be able to supply the energy system of the schooner for a minimum period of 24 hours sailing.

Once the number and different type of loads have been established, the next procedure is to establish the proper calculations for the sailing operations to achieve the correct amount of energy needed during a established period of 24 hours, considering the total amount of time each load has been operating during one day. These steps and calculations are developed furthermore in the second section of “*Calculation”, “2.4. DC & AC grid Electric Balance & Calculations of the Battery Banks & the Inverter*”.

b) Battery Bank & Features

The next process is to calculate and establish the Battery Banks. For this process of calculations there are a few steps, and considerations that must be taken into account to be able to acquire the correct final values. These steps to achieve the desire results are explained, and exposed on the second section of "*Calculations*".

Another section to develop is the type, and features of the battery that must be chosen for the installation of the schooner, and which are its operation properties. Thats why it is important to go through a selection process, where different types of battery models which could be appropriate for the project are compare between each other.

First of all the flooded lead acid (FLA) batteries which are the cheapest and more common on boats, have been discarded of being selected for the storage system of the schooner, because of their need of high maintenance, their great self-discharge rate and their low tolerance towards vibrations.

The Gel batteries have been discarded as well, because they have a lower effective capacity at higher discharge currents, also they must be charged carefully at a very low voltage rate, to prevent high voltage overcharging.

The AGM (absorbed glass mat) are an interesting possibility, but once they are compare with the Lithium-Ion batteries, the result establishes that the AGM have a lower depth of discharge, they must be around four times heavier to store the same amount of energy than the Lithium-Ion batteries.

Also Lithium batteries have a higher and much more stable terminal voltage, which allows the system to adapt towards different variating loads, and it even increases its useable energy at higher loads due to higher and more stable terminal voltage. Another important fact to take into account is the superiority of the Lithium batteries charge efficiency and rate. Because charging the last 20 % of a lead acid is alway slower and inefficient, consuming much more and for a greater period of time.

Through the study and research of the different batteries another different battery needs to be highlighted, from the brand "*Mastervolt*", which also applies to the requirement needed on board. We are talking about the "*MLI Ultra 24/5000*". It is composed of LiFePO4 (Lithium-iron phosphate) cells, protected by a strong waterproof housing for harshest conditions.

It includes the "Battery Management System" (BMS), that provides the optimal used of each battery allowing fast charge and discharge, giving you constant information of the state of the battery. It also has "*MasterBus/CAN*", which communicates with the battery charger to ensure the finest recharging and lifetime of your battery.

Figure 1. *The MLI Ultra 24/5000. Image by Mastervolt BV. (2020).*

General Specifications	
Nominal battery voltage	26.4 V
Nominal battery capacity	180 Ah
Nominal battery energy capacity	5000
Maximum charge current	500 A (2,8 C)
Continuous discharge current	500 A (2,8 C)
Peak discharge current	1800 A (10 C) for 10 s
Technical Specifications	
Battery chemistry	Lithium Iron Phosphate
Protection degree	IP65 (electronics cabinet)
Parallel connection	Yes, unlimited
Series connection	Yes, up to 10 batteries (series balancing up to 2 batteries)
Protections	Over voltage, under voltage, over temperature

Table 1. *General & Technical Specifications of the MLI Ultra 24/5000. Informations by Mastervolt BV. (2020).*

The "MLI Ultra 24/5000" applies with all the needed specifications and requirements for this project, but are way to expensive batteries, which would extremely increase are budget.

For this specific installation the Lithium Ion Batteries have been chosen, which preforms high-deep cycles thanks to their patented Lithium Iron Manganese Phosphate chemistry by Lithium Battery Power. According to our further exposed calculations, we have chosen a 12 V, 300 Ah Deep Cycle Lithium Battery, which combining two batteries in series the desire 24 V system is acquired.

The Features of the "LBP12V300Ah" Lithium Ion Battery are the following:

Battery Features	Benefits of Lithium Battery Power
> 4000 Cycles at 80 % depth of discharge	Save weight and space
Create systems 12-1000 Volts	Enjoying rapid charging and longer run time between charges
Series and/or Parallel operation	Replace your Batteries less frequently
Automatic system cell balancing	Increase your boat top charging speed
IP56 water and dust resistant BCI Group 8D case	10 year warranty
Temperature monitoring	Economic Savings
Exceptional voltage stability	-
Rugged mechanical design	-
Maintenance free	-
No hydrogen generation or gassing	-
<70 % the weight of similarly sized SLA batteries	-

Table 2. *Battery Features and Benefits, information by Lithium Battery Power Company.*

BATTERY SPECIFICATIONS	
Model	LBP300
Group Size	8D
Nominal Voltage	13.8 V
Charge Voltage	14.4 V to 14.6 V
Max. Charge / Discharge Current	100 A (amps)
Cold Cracking Amps	3000 A (amps)
Type	Li-Ion

Table 3. *Battery Specifications, information by Lithium Battery Power Company.*

Figure 2. *The LBP12V300Ah Deep Cycle Lithium Ion Battery, image by Lithium Battery Power.*

PERFORMANCE	
Usable Capacity (amp hours)	300Ah
Depth of Discharge	100 %
Peaks Amps 5 seconds	2000A (amps)
Reserve Minutes at 20 A	900
Reserve Minutes at 100A	240
Self Discharge	<3% a year
Capacity % at 100 cycles	102 %
Capacity % at 500 cycles	96.3%
Capacity % at 1000 cycles	90.8%
Capacity % at 1500 cycles	85.4%
Capacity % at 2000 cycles	80.1%

Table 4. *LBP12V300Ah Battery Performance, information by Lithium Battery Power Company.*

Thanks to the proper values of the Battery Features, on the section two of "Calculations", specifically part "*2.4. DC & AC grid Electric Balance & Calculations of the Battery Banks & the Inverter*", all the steps, and processes to calculate are exposed, and after we are able to proceed on the designs of the Energy Storage System.

	Number of Units	**Voltage**	**Total Absorbed Power**	**Number of Daily Used Hours**	**WattsHour/ Day**	**Amp.Hour/ Day**	**WattsHour**	**Amp.Hour**	**Total Power + 50 % Margin of Discharge**	**Ah/Day + 50% Margin of Discharge**	**Design Ah/Day Used On Our Batteries**
Receiver	**Total**	**V**	**W**	**Hours (h)**	**Wh/ Day**	**Ah/ Day**	**Wh**	**Ah**	**Wh/ Day**	**Ah/ Day**	**Ah/ Day**
Final Value	166	24	10296	80,5	67227	2801	2801,13	116,714	134454	5602	6000

Table 5. *Total DC Energy Storage needed for our Battery Banks. Table by the author.*

c) Charging & Inverter System

For the charging and inverter system, another selection of the most efficient and adaptable devices has been done, taking into account the features of the selected battery.

For the "*MLI Ultra 24/5000*" batteries the most compatible and efficient charger/inverter system would be the "*Mass Combi Ultra 24/3500-100 (230 V)*". For higher capacities the 35 kW model can provide used in parallel and on three-phase configuration.

"*The new inverter technology ensures a uniquely low stand-by use, while an ultra-fast Digital Signal Processor guarantees seamless switching between all available energy sources*."

Its intelligent transfer system allows a constant energy supply, playing with the generators and the inverter power supply ensuring a constant flow of energy in any possible situation.

Figure 1. *Mass Combi Ultra 24/3500-100 (230V). Picture by Mastervolt BV. (2020).*

Specifications sine wave Inverter	
Nominal DC voltage	24 V (19-32 V)
Output voltage	180-260 V, adjustable
Output frequency	50/60 Hz (± 0.005 %), configurable
Output waveform	true sine
Continuous power at 40 °C / 104 °F, cos phi 1	3500 W
Max. peak load	7000 W
Max. efficiency	≥ 92 %
Max. ripple on DC (battery at full load)	< 5 %
Specifications battery charger	
Input voltage range	184-275 V
Maximum input current	16 A
Maximum charge current	100 A at 28.5 V, adjustable
Specifications transfer system	
AC input (generator)	50 A (switched)
AC input (mains)	30 A (switched)
AC output 1	67 A
AC output 2	50 A (switched)
Transfer voltage range	184- 275 V, adjustable
Transfer frequency range	35-68 Hz, adjustable

Table 1. *Specifications of the Mass Combi Ultra 24/3500-100 (240 V). Information by Mastervolt BV. (2020).*

The "*Mass Combi Ultra 24/3500-100*" is a very interesting device which would apply perfectly to the installation of the schooner, but is not the most compatible charging/inverter system for the selected battery.

To supply the storage system of the schooner, which is the most efficient and compatible device according to the battery charging specifications of the "*LBP12V300Ah*" for 100 Amps, an to be able to charge the batteries on a minimum period of time, we have decided to use the "V*ictron Energy Quattro charger/inverter*", model "*8000VA*".

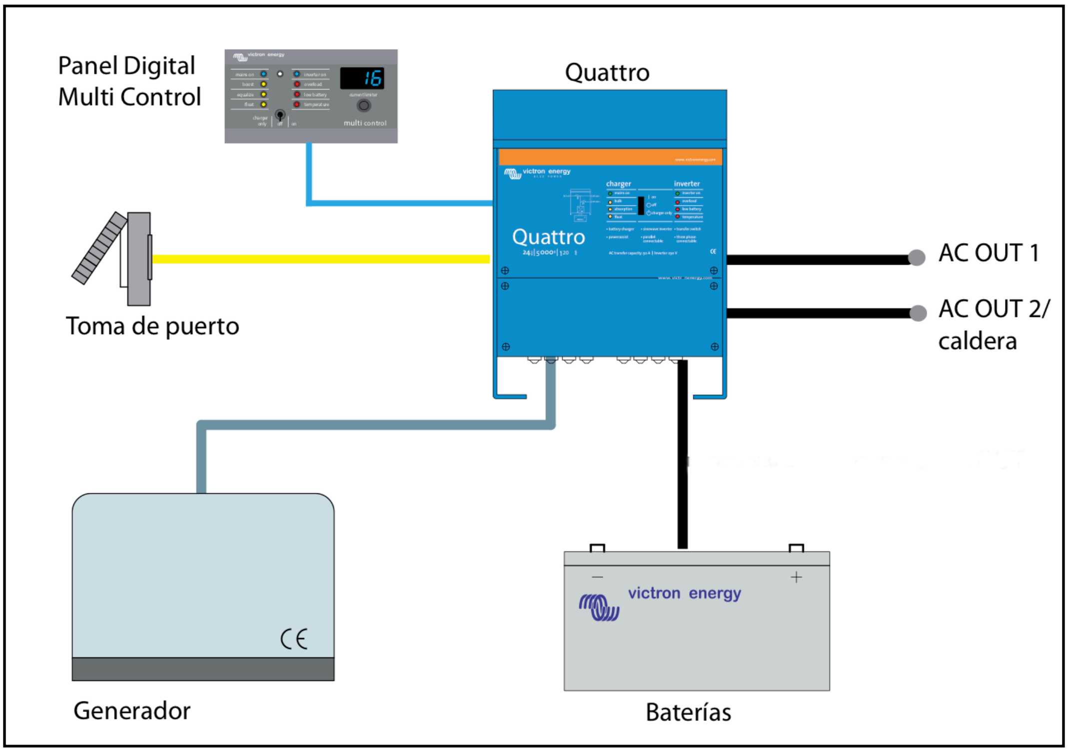

Figure 2. *Victron Energy Quattro charger/inverter, model 8000VA. Picture by Victron Energy Blue Power.*

The storage system is divided into 10 Battery Banks, with a total of 6000 Ah. Each battery Bank is composed of 2 batteries of 12 V & 300 Ah in series, creating total energy per battery banks of 24 V & 600 Ah.

An important factor to take into account is that we are going to try to discharge the batteries only until the 50 % of their capacity. This margin was already applied while acquiring the final calculations, and designs of the storage system.

So the total Ah which that the charging system must apply is 3000 Ah, to fully charge the 50 % discharge batteries. Also the chosen Quattro gives as an open installation range, specifically as described on the following quote by Victron Energy Blue Power.

"Three phase capability Three units can be configured for three-phase output. But that's not all: up to 6 sets of three units can be parallel connected to provide 162 kW / 180 kVA inverter power and more than 2500 A charging capacity".

The Quattro System is equipped with a functions, which allows to connect them in parallel, to provide a better energy supply to our, AC & DC-Grid. It only needs the proper number of Quattro's to be install, plush the proper software configurations, to efficiently supply the storage system, and through it supply the DC & AC loads.

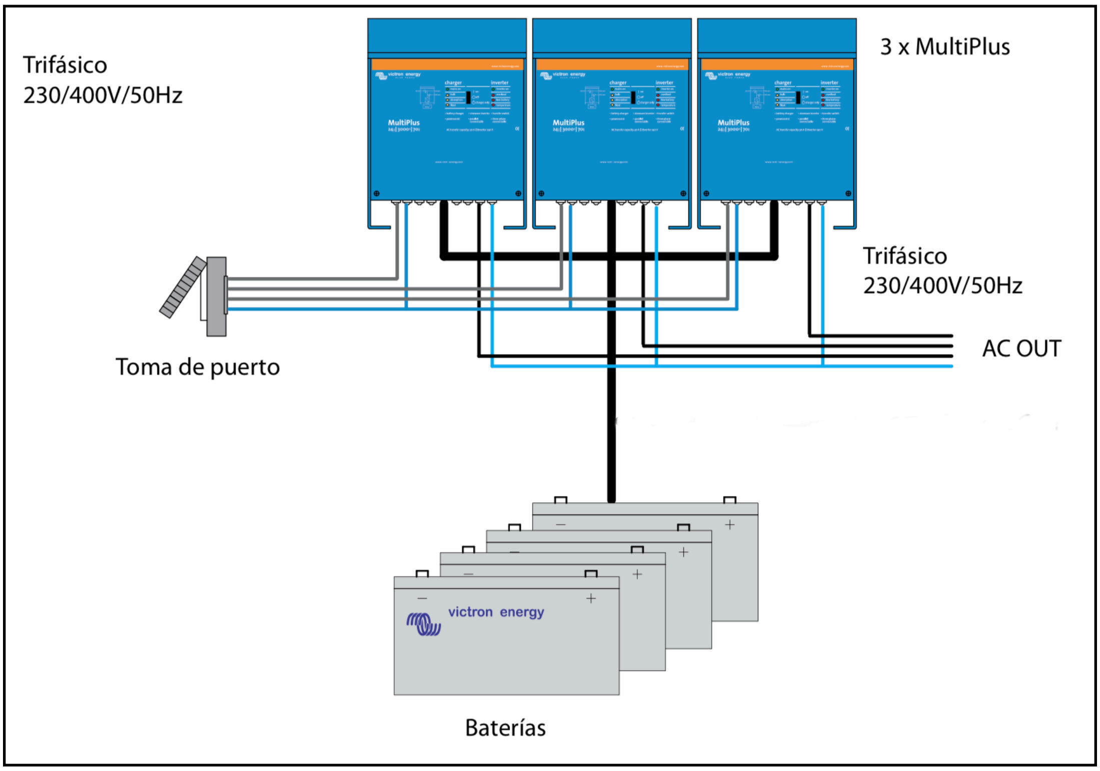

Figure 3. *Victron Energy Quattro charger/inverter, parallel function. Picture by Victron Energy Blue Power.*

Quattro 8000VA	
PowerControl / PowerAssist	Yes
Transfer commutator integrated	Yes
2 entrances CA	Voltage entrance range: 187-265 VCA Entrance Frequency: 45 – 65 Hz Power Factor : 1
Communication Gate VE.Bus	For parallel & three-phaser function, remote supervision & system integration
Maximum current (A)	2x100
Inverter	
Entrance Voltage (VCC)	9,5 - 17 V 19 - 33 V 38 - 66 V
Exit	Exit volage 230 VCA ± 2% Exit Frequency 50 Hz ± 0,1%
Constant Power (VA)	8000 VA
Constant Power (W)	6500 W
Maximum Power (W)	16000 W
Charger	
Absorption voltage (VCC)	28,8 / 57,6
Flotation voltage (VCC)	27,6 / 55,2
Bulk voltage (VCC)	26,4 / 52,8
Charging current (A)	200 / 110
Temperature battery sensor	Yes

Table 2. *Specifications of the Quattro 8000VA. Table information by Victron Energy Blue Power.*

The Quattro is also provided with a "*no-break, (without interruption)*" function, which in case of a AC-Supplied generator breakdown, the main electric devices will still be operating, through a change of the power supplied. The changed is made in less than twenty milliseconds by the Quattros through the energy storage in the Battery Banks. This function stabilises the whole electric network on board.

1.9. Implementation of the Hydrogenation system

This section establishes the technical study applying a hydrogenation system to the generation plant of the schooner. While sailing this additional energy generation system is able to reduce the diesel consumption of the generators, and with it their emissions and their running hours. As well this system increases the using time of the energy storage system, increasing the efficiency of the installation, bounding it together with economic benefits, and a decrease in the maintenance and its wastes. The implementation of these devices generates energy created throughout a much cleaner process, and free of contamination.

The hydrogenation system of the schooner consist of two electric brushless motors, attached on the ship's hull sides, under neath the waterline closed to the keel. The hydrogenations are designed with its corresponding optimise propeller size and pitch, to achieve the proper number of rpms for an average sailing speed of 10,5 knots. While sailing the propeller, which is attached to the rotor of the electric motor, transforms the mechanical energy into electricity through its stator. So this system is using those electric motors as hydrogenerators.

For the dimensions and specifications of the schooner the acquired hydrogenations are a two electric brushless motors of 10 kW each. These stablished that the hydrogenerators have the maximum size and power recommended by "*ARKA Electric Propulsion*", so they won't become a friction and resistant problem for the schooner aerodynamics. The hydrogenerators are installed one on the Starboard side, and the other one on Port side, as it can be seen in the "*Figure 1. Hydrogenerators on each Section of the Hull*" . The selected electric brushless motors for the technical study of the schooner contains the following features developed on the next following section.

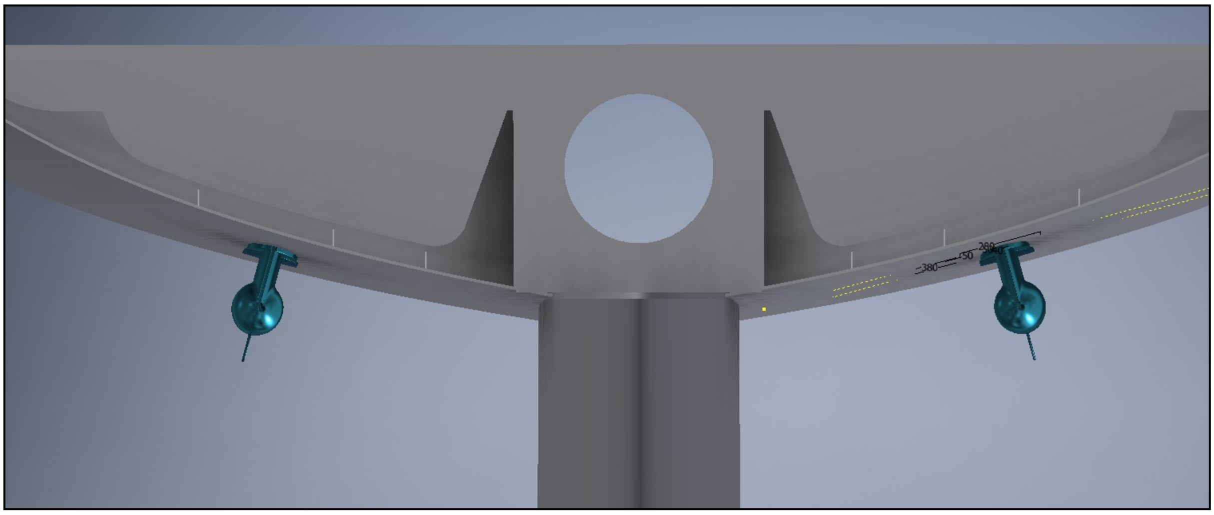

Figure 1. *Hydrogenerators on each Section of the Hull. Picture by SY Windrose of Amsterdam.*

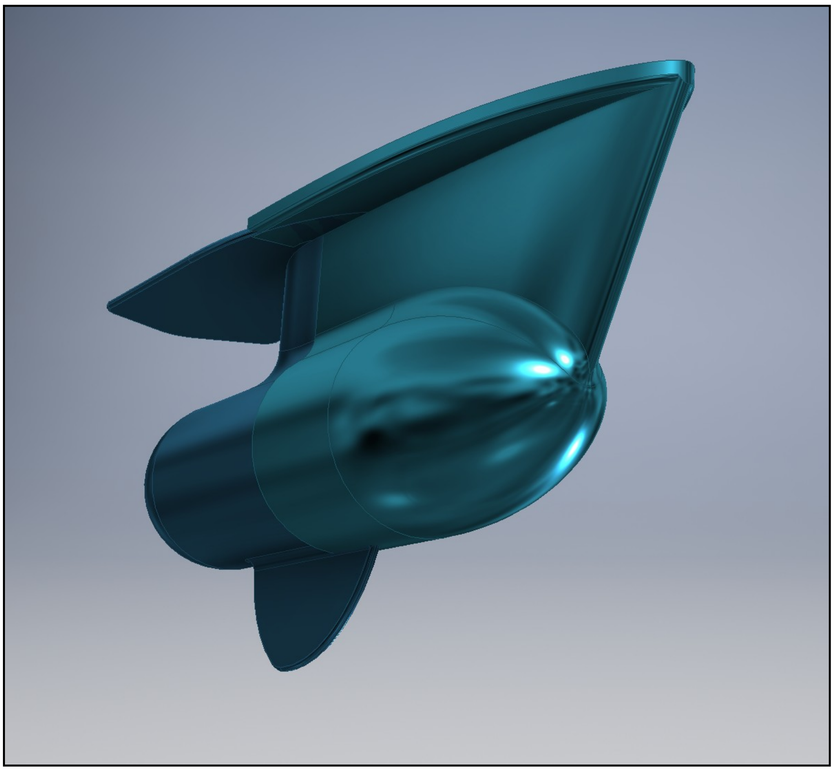

Figure 2. *POD Aerodynamic Estructure Design, picture by SY Windrose Of Amsterdam.*

a) Feature of the hydrogenerator

The features of the hydrogenerators are the values, used to calculate the estimated energy generated from each device while sailing. These values of this specification table, "*Table 1. Features of the ARKA POD 10 kW*", are estimated results compere to the real values which must be obtain during its real use while sailing.

MODEL	**ARKA POD 10 kW**
MOTOR	
Type	Brushless DC PMSM
Continues Power	10 kW
Voltage	80 VDC
Couple	65,9 Nm
rpm	1500 rpm
REGULATION	
Type	4
Maximum Current	550 A
Current	220 A
Capacity	18 kW
Operating Voltage	72-80 VDC

Table 1. *Features of the ARKA POD 10 kW. Information by ARKA Electric Propulsion Systems.*

The estructure of the PODs, must flow accordance to the hull design, to make it as much hydrodynamic as posible. Also the proper distance from the hull, towards the POD's propeller shaft must be optimise.

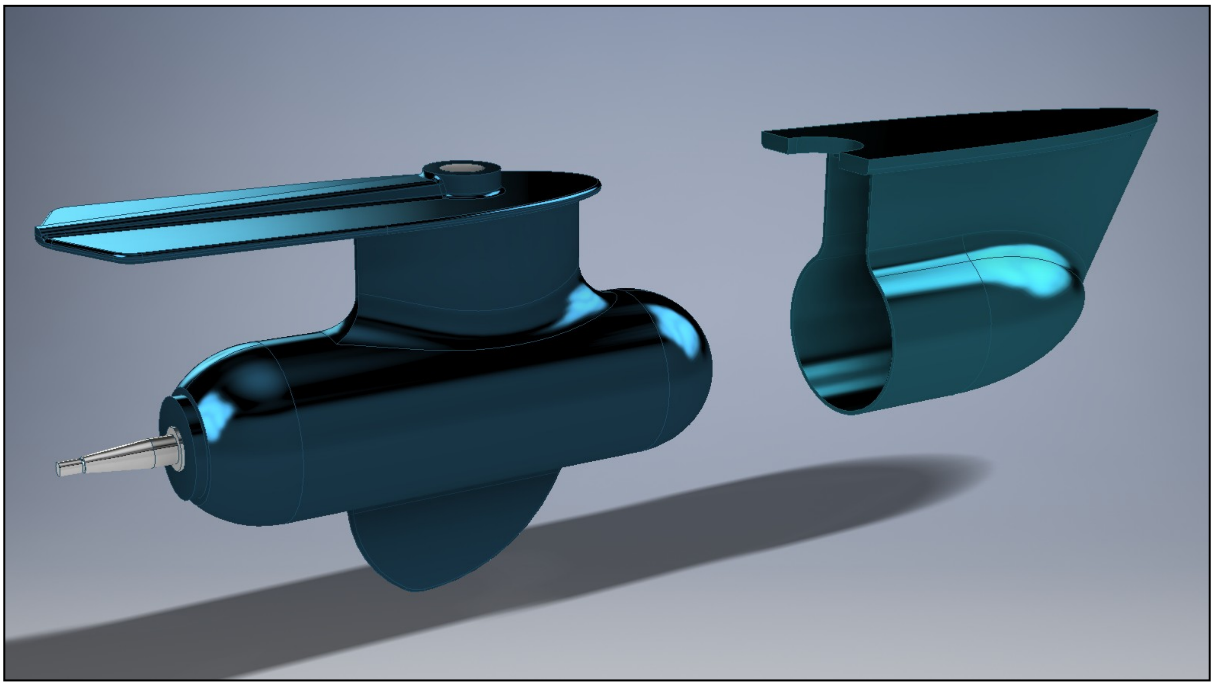

Figure 3. *PODs & Hull Estructure Design, picture by SY Windrose Of Amsterdam.*

b) Power Generated by the Hydrogenerators

The total result of the generated power is an estimated value, which in reality is going to be fluctuating at different ranges, depending on the diverse weather changes, and factors, which will affect on the efficiency of the hydrogenerators created power.

To acquire an acceptable estimated value, on a such variable generated power, it is necessary to apply an operating efficiency ratio, for this reason it has been applied a 75 % of efficiency to the hydrogenerators generated power.

The steps and conditions to achieve the proper generated power from the hydrogenerators are explained further more on the section two of "*Calculations*". From those calculations and features the final power generated approximated results are shown in the "*Table 2. Total Estimated Generated Power by the Hydrogenerators*" underneath.

Type	Number of Hydro-generators	Continues Power	Continues Current	Total Continues Power	Total Amps. Hour	75 % Of Power Efficiency	Total Power During 24h	Total Amps/ Hour during 24h
	N	**kW**	**A**	**kW**	**Ah**	**kW**	**kW/Day**	**Ah/Day**
PMSM	2	10	220	20	440	15	360	7920

Table 2. *Total Estimated Generated Power by the Hydrogenerators. Information from ARKA Electric Propulsion & Calculations by the author.*

An important factor to take into account is that the amount of load applied to each hydrogenerator can be regulated. Playing with the schooners sailing speed, and the desire generated load let us improve the efficiency for every different situations, and achieving an almost constant number of rpms.
Each hydrogenerator has a switch to connected to the Battery/Inverter busbar, to transform and store that energy in the most efficient way into the storage system. In the following picture "*figure 4, Electric energy distribution on board the schooner*", it is possible to appreciate the connections of the energy distribution network of the schooner.

On the next picture "*Figure 5. Distribution of the whole energy system on board the schooner*", there is a whole over view of the distribution of the diesel generators, the hydrogenerators (ARKA Pods PMSM), the battery banks and the Quattros on board the schooner. Followed by three more figures "*Figure 6 , 7 & 8*" which exposed the electrical scheme of the schooner.

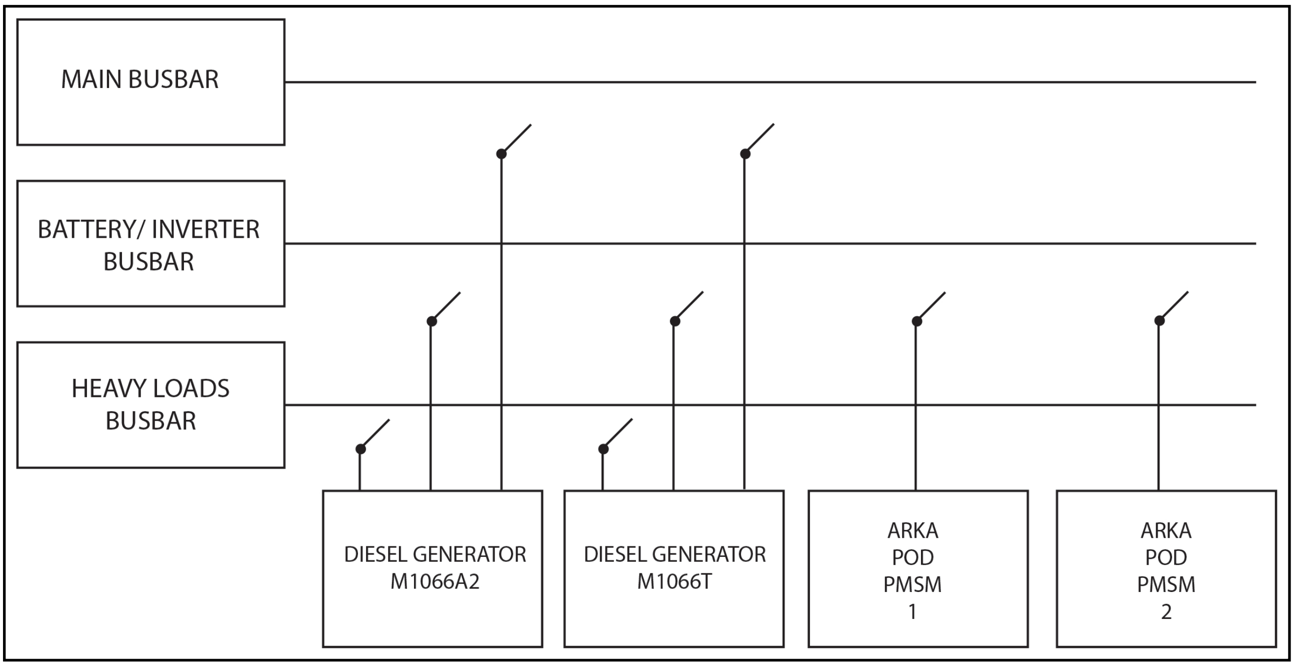

Figure 4. *Electric energy distribution on board the schooner. Picture by the author.*

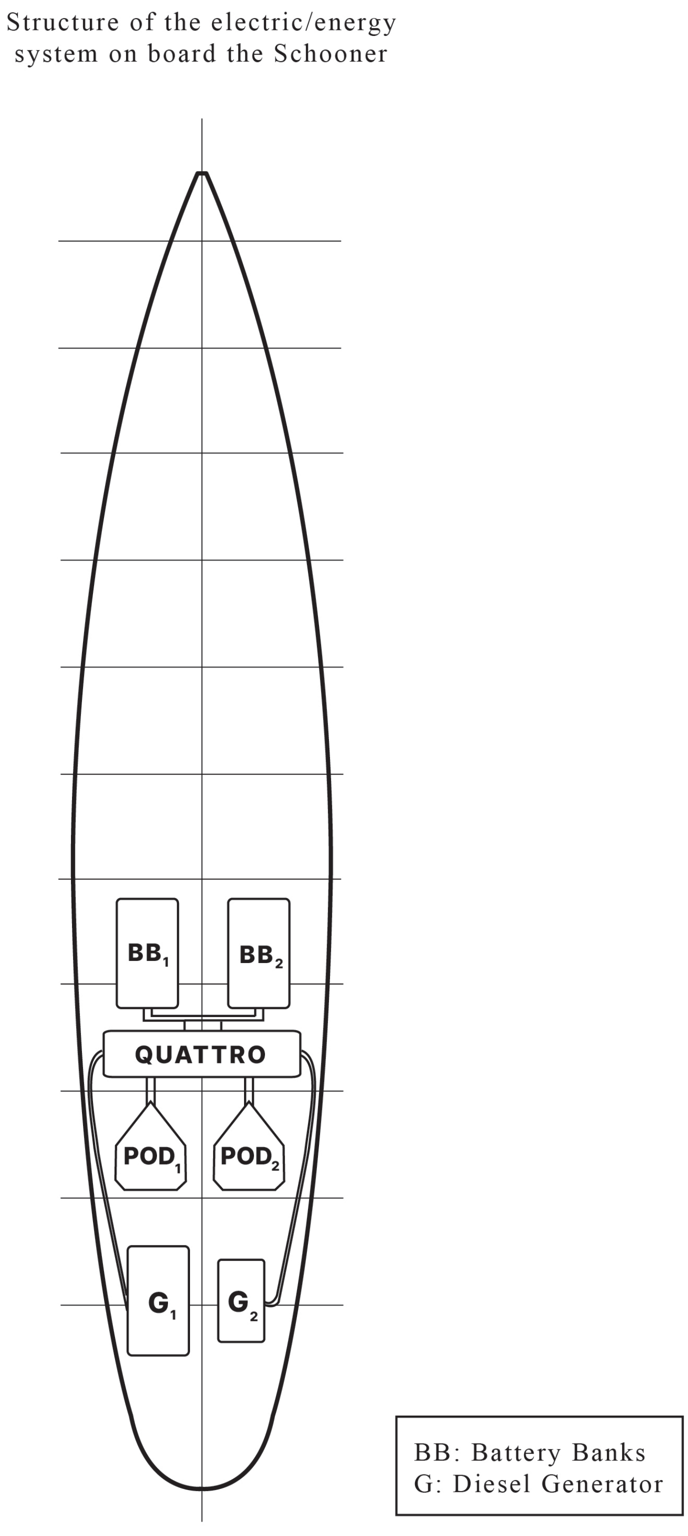

Figure 5. *Distribution of the whole energy system on board the schooner. Picture by by the author.*

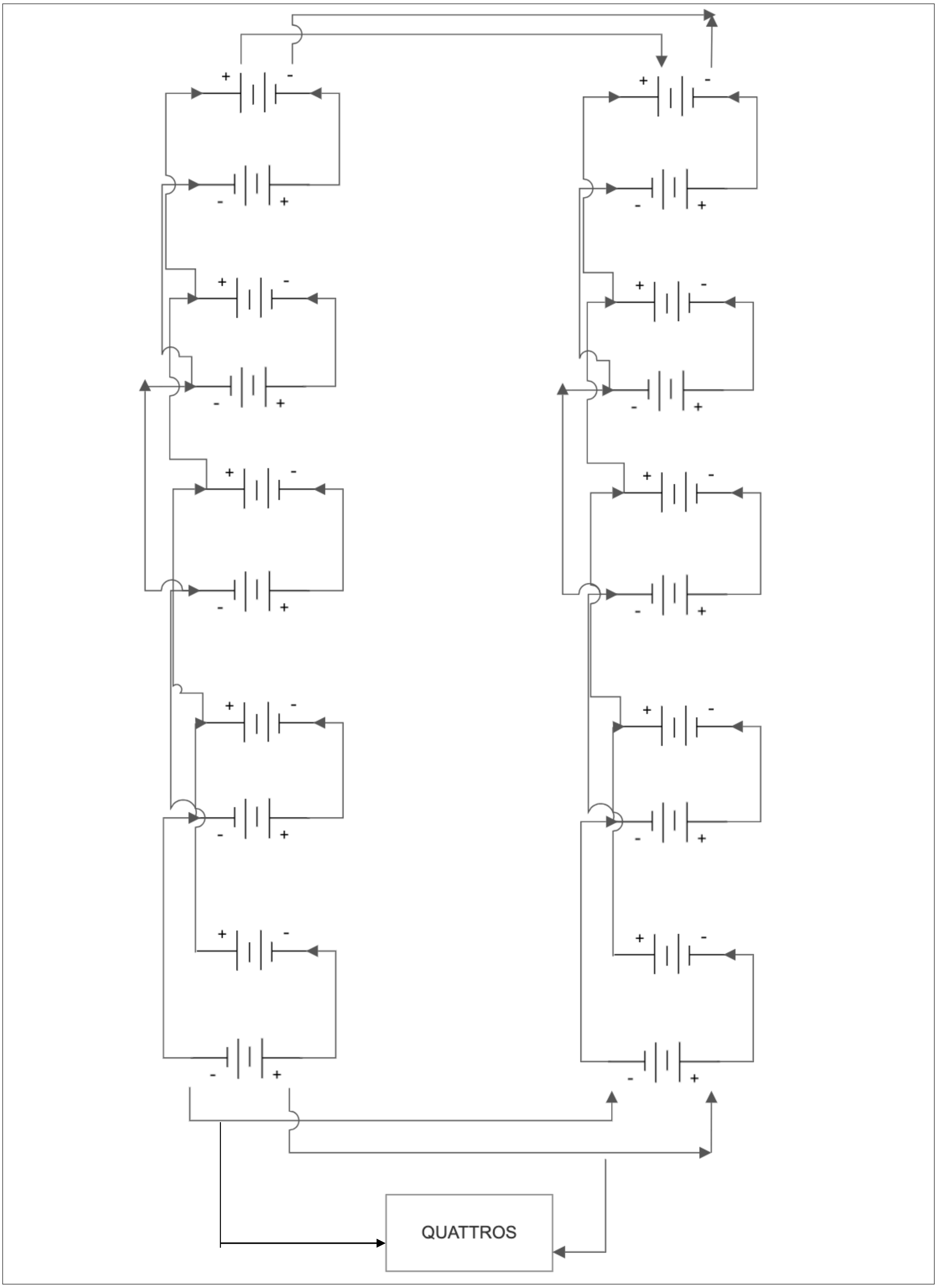

Figure 6. *Battery bank configuration of 10 battery banks in parallel of two batteries of 12 V 300 Ah in series connected to the Quattros. Creating a 24 V 6000 Ah system. Figure by the author.*

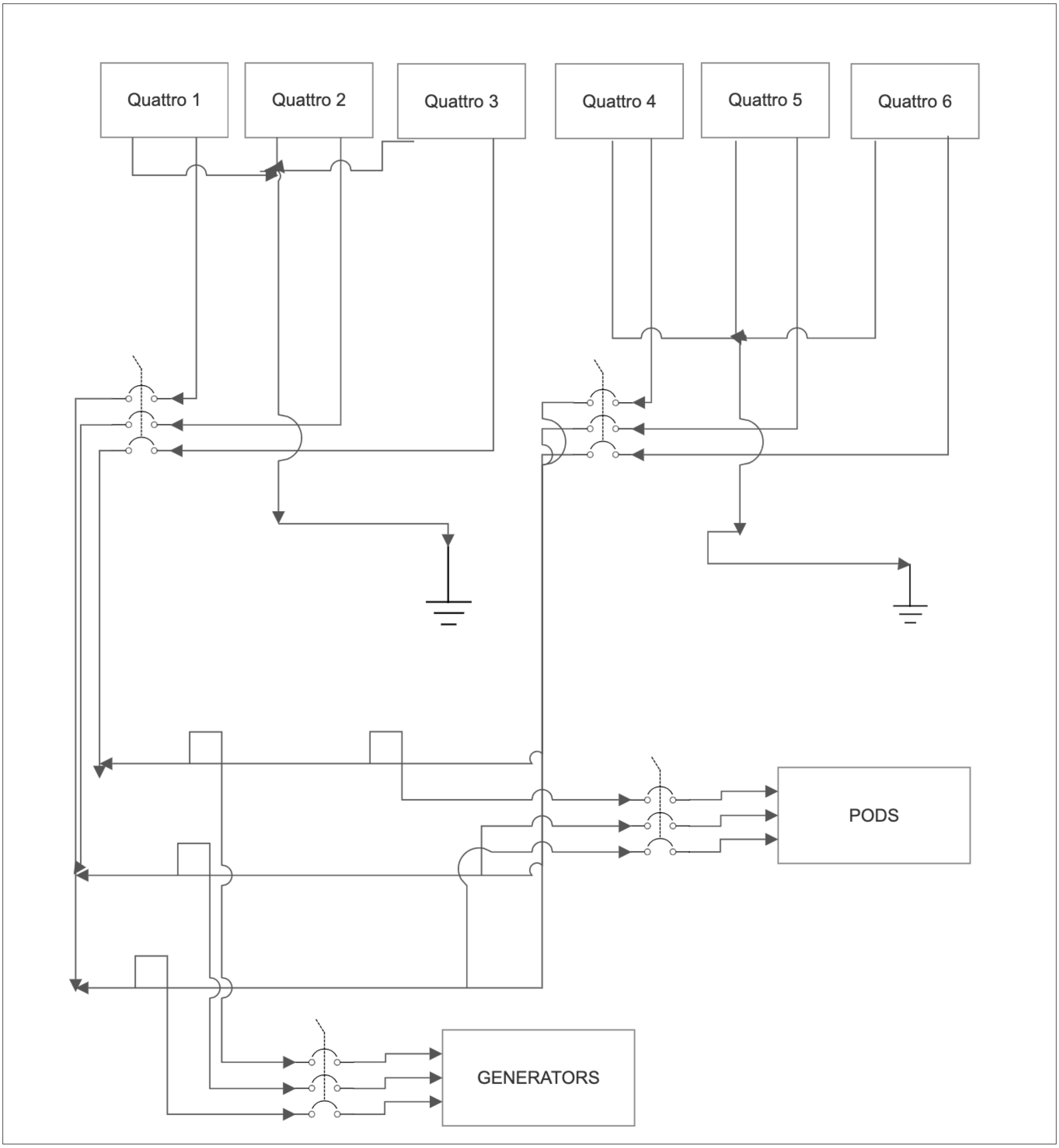

***Figure** 7. Generators, PODs & Quattros electric scheme connection. Figure by the author.*

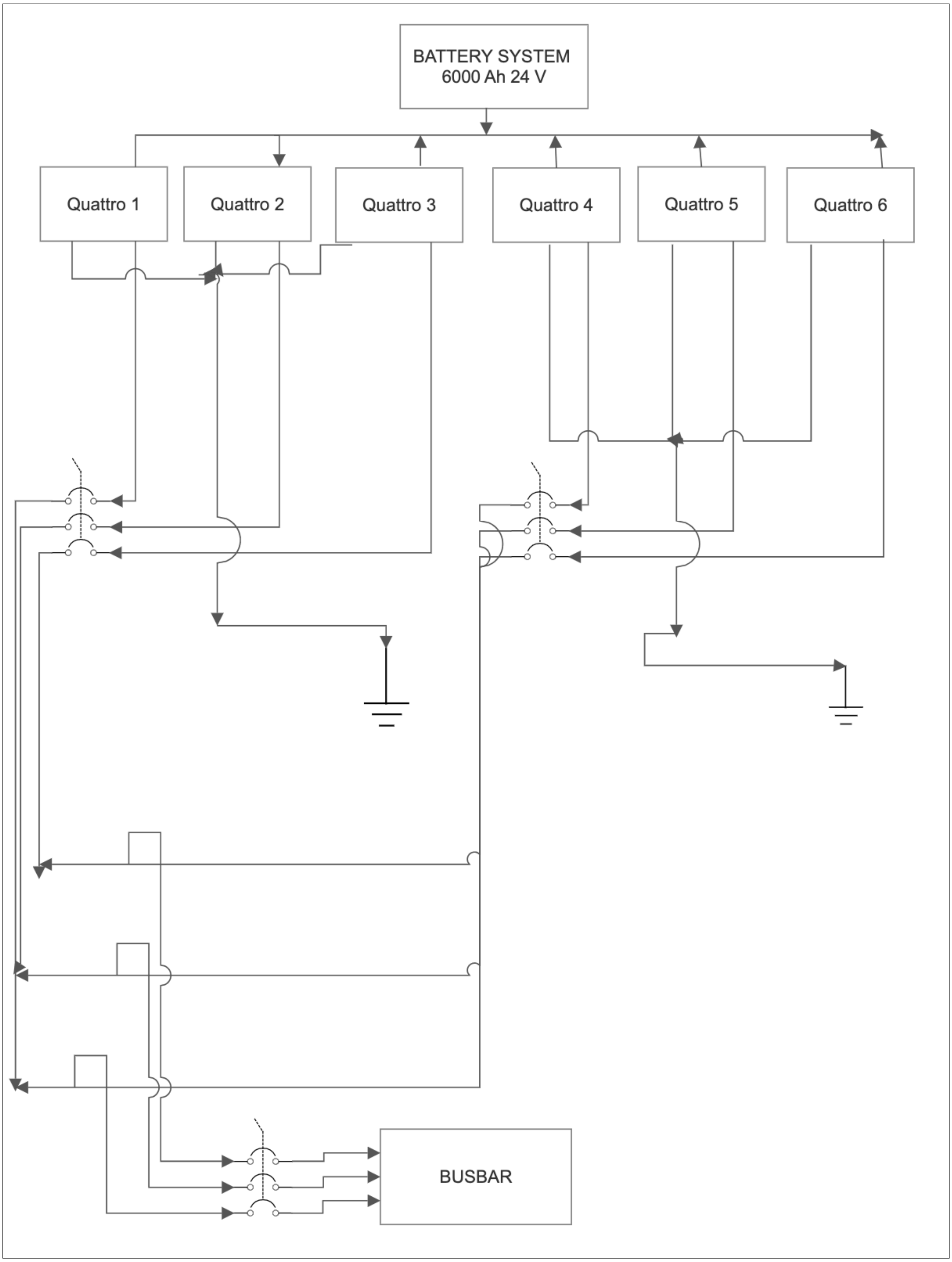

Figure 8. *Electric scheme of the battery system connected to the Quattros & the AC three-phase inverter distribution towards the Busbar. Picture by the author.*

2. CALCULATIONS

2.1. Introduction

This Section exposes the different processes, calculation, and methods used to achieve the results needed to design and develop the technical study of the generating and storage system of the schooner. Thats the reason why is divided in divers categories.

The first category defines the creating process of the electric balance, with its determined power consumption calculations, specifically for each type of operation.

Once the electric balances have been established for the different operations, and the results of the main operations with the highest values of the absorbed power consumption have had been selected, the average generators consumption is established.

Along with the generating plant the calculations to design the energy storage system, specifically the capacity and power of the battery banks and inverters can be implemented.

2.2. Features of the Electric Balance

a) Installed Power & Absorbed Power

The Installed Power is equivalent to the Nominal Power of each device, so when we talk about the Total Power Installed, we are talking about the sum of the Nominal Power of every single load on board.

$$TotalPowerInstalled = (sum)NominalPowerReceptors$$

Equation 1. *Calculations established by the author.*

It is necessary to be provided by the Power Installed of each device and their Utilisation Factor (Ku). Which is the relationship coefficient of the total used time, compare to the full load time, ($Ku < 1 or Ku = 1$). *Ku* varies with each different load state. This fact, which is needed to take into account, occurs because the receptor is not working all the time at *100 %* of its load demand capacity. So to acquire the Absorbed Power, we multiply the Power Installed of each receptor with its correspondent *Ku*. We need to repeat this process with every different receptor, and then we put together the results of the all Absorbed Power values of each load and we achieve the Total Absorbed Power.

$$AbsorbedPower = KU * PowerInstalledReceptor$$

Equation 2. *Calculations established by the author.*

b) Active, Apparent & Reactive Power

Further in the Electric Balance we calculate not only the Total Absorbed Power, which is equivalent to the Active Power (Kw), but also we calculate the Reactive Power (KVAr), that's an independent power formed by capacitive or inductive loads, typical of electric motors. Thats why we need to take into account the Power Factor ($cos(\phi)$) for each receptor, and include the results into the Electric Balance. The Power Factors usually varies between 0,75 all the way to 0,9.

To be able to calculate the proper average Power Factor for the installation, it is required the sum of the different Power loads, acquiring the Active & Reactive Power of the Installation. But most of the time the Power Factor is already given by the device.

$$cos(\phi) = ActivePower/AparentPower$$

Equation 3. *Calculations established by the author.*

c) Calculation Steps of the Electric Balance

	Load Type	Number of Units	Power Installed	Total Power Installed	Utilisation Factor	Total Absorbed Power (P)	Power Factor	Total Reactive Power (Q)	Total Apparent Power (S)
Receiver	**Phase**	**Total**	**kW**	**kW**	**Ku**	**kW**	**cos(ϕ)**	**kVAr**	**kVA**
Load nº1	Three-Phase	2	1,1	2,2	0,8	1,76	0,8	1,32	2,2
Load Name	N-Phase	N	Kw	$N * Kw = P$	X <1	X * (N*Kw)	Y <1 Or Y = 1	$\sqrt{(S^2 - P^2)}$	P/ cos(ϕ)

***Table 1**. Example & Steps used to calculate the values of the Electric Balance. Table by the author.*

2.3. Calculations & Steps to design the Generating Plant

a) Amount of Supply Power Generated

Through the Electric Balance the minimum amount of power to supply is fixed. The lowest value that the generating plant must be able to supply is equivalent to the maximum load state of demand. It must be consider that the result of the Electric Balance is not the final value, there are a few facts, which must been taken into account.

It is wise to leave a reasonable extra margin into the calculations. Throughout the life of the installation, the Power Installed of all the devices will smoothly increase constantly year by year. This is caused by the ageing of the devices, like electric motors, causing an increase in the energy consumption, due to a decrease in the efficiency of the loads.

For these reasons the engineers decided to increase the final values, of the previous calculations, to a 4 or 5 percentage of the Total Absorbed Power, to ensure the proper amount of generated power, and acquiring a better optimise number of generators, a more efficient storage system and a greater amount of power for every single operation.

This final value must not be consider as a safety margin. This final safety percentage will be added in the selection of the generators, once the number and dimensions of the generating plant have been previously calculated and designed before the realisation of the technical study.

Following the previous considerations, and the previous Electric Balances calculations for the different load operations, which are classified into "*Navigation Loads, Manoeuvring Loads, Extra Daily Loads, and the Total Power of the Installation*".

The final result of the Total Power Absorbed for each different operation, it is stablished in the following table of contest "*Table 2. Final Electric Balance results of the main different Load Operations*". These values are the ones that must be taken into account to calculate, design, and establish the technical study of the storage system and installation of the hydrogenation system of the schooner.

Number of Units	***Number of Units***	***Power Installed***	***Total Power Installed***	***Utilisation Factor***	***Total Absorbed Power (P)***	***Power Factor***	***Total Reactive Power (Q)***	***Total Apparent Power (S)***
Units	***Total***	***kW***	***kW***	***Ku***	***kW***	***cos(ϕ)***	***kVAr***	***kVA***
Total Installation Power	185	129,2	173,7	0,819	141,526	0,824	95,029	173,325
Total Nav. Power	98	23	40,1	0,795	30,064	0,808	21,961	37,231
Total Manoeuvr Power	89	88,4	96,2	0,856	81,512	0,840	54,470	97,038
Total Extra Loads	83	26	44,1	0,815	36,43	0,826	22,183	43,725

Table 2. *Final Electric Balance results of the main different Load Operations. Calculations by the author.*

b) Number and Dimensions of Generators to Install

Although this process has been stablished before the realisation of this technical study it is a point that I would like to take into account and develop an explanation. Leaving this section as an example and a recompilation of concepts of how to design and acquire the most optimise and efficient generating plant.

It is possible to design a generating plant with a single generator, but it must be divided into two or more generators. It is not reasonable to put all the trust in a single generator, because at the minimum break down the whole system would be shutdown, putting in danger the whole vessel.

Also the SOLAS specifies that the vessel must dispose of at least two generators capable of supplying the schooner for the maximum possible demand, needed in case of manoeuvring with one of the generators on stand-by or out of service.

The most common method is to distribute the Total Absorbed Power of the maximum load demand into “n” generators with the same power, so in case of failure of one of the generators (n-1), the remaining generator can keep supplying the system.

To determine the number of generators “n” we use the previous established values with the most efficiency adaptability for the installation.

First of all we select the greatest Operational Load consumption, which in our case is during Manoeuvring. To this value we must add the Total Extra Loads, which could be connected during any situation.

$$TotalGeneratedPower = ManoeuvringLoads + ExternalLoads$$

Equation 4. *Calculations established by the author.*

To the final result of the sum of those two different values we add an extra 5 % margin, stablished by the engineers.

$$FinalTotalGeneratedPower = TotalGeneratedPower * 1{,}05$$

Equation 5. *Calculations established by the author.*

With the final Total Generating Power results we can start establishing the number and dimensions of the generators, which are going to be established as the generating plant of the installation.

Number of Units	***Number of Units***	***Power Installed***	***Total Power Installed***	***Utilisation Factor***	***Total Absorbed Power***	***Power Factor***	***Total Reactive Power Q***	***Total Apparent Power S***
Units	***Total***	***kW***	***kW***	***Ku***	***kW***	***cos(ϕ)***	***kVAr***	***kVA***
Total Manoeuvr + Extra Loads	166	114,4	140,3	0,836	117,942	0,841	93,363	168,378
Total Generating Power (+ 5 % margin)	166	120,12	147,315	0,836	123,8391	0,841	98,03115	176,7969

Table 3*. Total Generated Power plus the 5 % margin added. Calculations by the author.*

The Generators must be capable of admitting an instantaneous over-voltage of the 50 % of the generated power during a period of 1 minute, and admitting a constant over voltage of the 20 % of the power during 2 hours. This value is a safety power gap that must be taken into account during the selection of type and number of generators.

For this reason we must divid the generated plant into two diesel generators capable of synchronise between each other, as shown on the "*table 4, Generated energy calculations of the selected generators*".

GENERATOR CALCULATIONS						
Type	**Frequency**	**Number Of Revolutions Per Minute**	**Total Generated Power**	**Total Synchronised Power**	**80 % Generated Power**	**80 % Total Synchronised Power**
Units	**Hz**	**rpms**	**kW**	**kW**	**kW**	**kW**
M1066T	50	1500	80	195	64	156
M1066A2	50	1500	115	195	92	156
Operations	Hz	Rpms	kW	80+115	0,8*kW	64+92

Table 4. *Generated energy calculations of the selected generators. Table by the author.*

The total generated energy by the two diesel generators, which creates the generating plant is established at 156 kW, operating on an 80 % load, making 195 kW the total maximum generated power, value which must be kept as a safety operating precaution.

The generated power of the diesel generators, compared to the total maximum energy consumptions of the whole loads has the following margin of power.

$$SpareGeneratedEnergy = 156kW - 121{,}1kW = 34{,}9kW$$

Equation 6. *Calculations established by the author.*

c) Hydrogenation System Generated Power

To be able to calculate the hydrogenation system generated power, first of all we must used the proper specifications features of the selected hydrogenerators, developed on the previous section *"1.9. Implementation of the Hydrogenation System"*, specifically on the "*part b, Power Generated by the Hydrogenerators"*. With that basic necessary information we can proceed to calculate the estimated generated power.

We must be clear with the amount of hydrogenerators, which we want to install, and the percentage of efficiency performance that each one of the devices is going to generate. For the efficiency number we have approximately chosen the total value of 75 % efficiency as "ARKA Electric Propulsion Systems" has recommended.

$$TotalContinuesPower * 0{,}75 = 75EfficiencyOfGeneratedPower$$

Equation 1. *Calculations established by the author.*

The following table "*Table 1. Calculations Of the Generated Power by the ARKA PODs PMSM*" exposes the basic calculations made, to acquire the Total Generated Power from the hydrogenation system.

Type	Num. Of Hydro.	Voltage	Capa-city	Max. Current	Cont. Power	Continues Current	Total Continues Power	Total Amps/ Hour	75 % Power Efficiency	Total Power During 24h	Total Amps/ Hour during
Units	**N**	**VDC**	**kW**	**A**	**kW**	**Ah**	**kW**	**Ah**	**kW**	**kW/ Day**	**Ah/ Day**
PMSM	2	80	18	550	10	220	20	440	15	360	10560
	N	-	-	-	kW	Ah	N * kW	N * Ah	(N* kW) * 0,75	(75 % kW) * 24 h	(N * Ah) * 24 h

***Table 1**. Calculations Of the Generated Power by the ARKA PODs PMSM. Features by ARKA Electric Propulsion & Calculations by the author.*

It is needed to establish a year around Total Power Generated by the hydrogenerators, to acquire the proper information to indicate the economic, and maintenance benefits, which we are going to achieve along with its storage system.

For a whole year, which is divided into 365 days, the schooner is going to sail for 170 days, in which from those 170 days, only the 80 % of those days approximately we are going to be able sail the other 20 % would be motoring, and preforming manoeuvres.

$$TotalSailingDays = 170Days * 0{,}8 = 144SailingDays$$

Equation 2. *Calculations established by the author.*

Along with the Total Sailing Days, we can proceed to calculate the total number of operating hours of the hydrogenerators generated energy.

$$TotalSailingHours = 144 * 24h = 3456Hours$$

Equation 3. *Calculations established by the author.*

The next exposed table of contest, "*table 2, Total Hydrogenation System Energy Generated*" shows the developed calculations for acquiring the total amount generated energy by the ARKA PODs PMSM, during the period of a whole year.

Type	Number Of PODs	Total Continues Power	Total Amps/ Hour	75% Of Power Efficiency	Total Power During 24h	Total A.Hour during 24h	Total Power During a Year (144 days)	Total A.Hour/ Year
Units	**N**	**kW**	**Ah**	**kW**	**kW/Day**	**Ah/Day**	**kW/year**	**Ah/Year**
PMSM	2	20	440	15	360	10560	51840	1520640
	N	kW	Ah * N	kW*0,75	kW/Day	Ah/Day	(kW/ Day)* 144	(Ah/ Day) * 144

Table 2. *Total Hydrogenation System Energy Generated during a one year period. Table by the author.*

2.4. DC & AC grid Electric Balance & Calculations of the Battery Banks & the Inverter

a) Calculations of the Electric Balance for the 24 V & 240 V, DC & AC grid

To Calculate the Battery System it is essential previously to acquire the proper Electric Balance for the 24 V DC Loads, plush the possible AC extra loads which we desire to supply with the storage system throughout the Quattro, during a period of 24 hours of sailing.

On the Electric Balance it is establish the number of units to supply, with its corresponding power consumption, and the operational used time of each device during a period of 24 hours.

Starting with the Total Absorbed Power. It is the result of the total used power for all the DC loads and extra AC loads of the system. This value is the one we will used to multiply by the number of hours each device is operating during a period of 24 hours. The result of this operation is the Total Power used every day through the storage system, this value is established by WattsHour/Day.

$$TotalAbsorbedPower * NumberOfDailyUsedHours = WattsHour/Day$$

Equation 1. *Calculations established by the author.*

The total *WattsHour/Day* final result, which the whole storage systems needs to supply must be multiplied by the voltage of the grid, which is 24 V for the DC loads or 240 V for the AC loads to acquire the total value of *AmpsHour* used daily throughout the installation, and further more calculate are Battery System.

$$WattsHour/Day * 24V = AmpsHour/Day$$

$$WattsHour/Day * 240V = AmpsHour/Day$$

Equation 2 & 3. *Calculations established by the author.*

Once the final value is been achieved, we must add a *50 %* of margin of discharging, to provide the batteries with a longer life time, and a more constant efficiency rage during every cycle. To acquire this result, the values must be multiplied by the total final results of the *WattsHour/Day*, and the total *AmpsHour/Day* final value times two.

$$WattsHour/Day * 2 = TotalPowerMarginOfDischarge(WattsHour/Day)$$

$$AmpsHour/Day * 2 = TotalAmpersHour/DayMarginOfDischarge$$

Equation 4 & 5. *Calculations established by the author.*

The following contest table "T*able 1, Electric Balance of the Total Power Installed on board*" exposes the processes, and calculations to acquire the 24 and 240 V-grid Electric Balance for the installation of the schooner. We repeat the coming calculation processes with every single load, which must be supplied by the storage system.

	Number of Units	Voltage	Current	Absorbed Power/ Unit	Total Absorbed Power	Number of Daily Used Hours	WattsHour/Day	Amp.Hour/Day	Total Power & 50% Margin of Discharge	Amp.Hour/Day & 50% Margin of Discharge
Receivers	**Total**	**V**	**A**	**W**	**W**	**Hours (h)**	**Wh/ Day**	**Amph/ Day**	**(Wh/ Day)**	**(Ah/ Day)**
Example Device	2	24	5	120	240	2	480	20	960	40
Calculations	N	24	A	W	Total N*W	Hours (h)	H * (N*W)	(Wh/ Day) * 24V	(Wh/ Day)*2	(Ah/ Day)*2

Table 1*. Example of the calculation process of the 24 V & 240 V loads. Table by the author.*

The final established results are the subsequently exposed values, which we will used to choose the type and size of the chosen Battery, and continuously design the Battery Bank for the energy storage system.

	Number of Units	Voltage	Total Absorb. Power	Number of Daily Used Hours	Watts Hour/ Day	Amp. Hour/ Day	Watts Hour	Amp. Hour	Total Power + 50 % Margin of Discharge	Amp.Hour/Day + 50% Margin of Discharge
Receiver	**Total**	**V**	**W**	**Hours (h)**	**Wh/ Day**	**Amph/ Day**	**Wh**	**Hours**	**(Wh/ Day)**	**(Ah/ Day)**
Total Values	0	24 or 240	1340	82,50	69627	2811	2901,13	117,13	139254,00	5802

Table 2. *Final Electric Balances Values, to Calculate & Design our Storage System. Table by the author.*

b) Features & Calculations of the Battery Bank

Continuing with the "*Table 2, Final Electric Balances Values, to Calculate & Design our Storage System"* values, we really need to pay attention to the the final amount of *AmpsHour/Day* of *5802 Ah/Day,* this final value is rounded to 6000 Ah/Day, so we have a small margin if we want to add any extra devices, and also is a more comfortable value to design the Battery Bank.

From the corresponding final results of the Electric Balance, we have chosen a 12 V 300 Ah Lithium Ion Marine Battery, which is one of the best batteries in the market that will adapt to our system, also because the the number of batteries needed would be 19,34 for 5802 Ah, follows the need of rounding that final value all the way to 20 batteries.

$$5802Ah/300Ah = 19{,}34$$

Equation 1. *Calculations established by the author.*

The selected Lithium Ion Battery, LBP12V300Ah, contains the following features, that will be used to design the Battery Banks together with the Electric Balance:

Lithium Battery Contest	Product	Voltage	Capacity	Weight	Dimensions	Max. Cont. Current	Max. Charging Current	Charge Voltage	Energy (Wh)
Units	**Type**	**V**	**Ah**	**Kg / lbs**	**L x W x H**	**A**	**A**	**V**	**Wh**
Values	12V 300AH Lithium Ion Battery	12	300	43,1 / 95	19.25" x 10.25" x 8.75"	144	100	14,4 to 14,6	1200

Table 1. *Features of the Lithium Ion Battery, LBP12V300Ah. Information by Lithium Battery Power. Table by the author.*

For calculating the number of batteries needed into the Energy Storage System, we used the total value from the Electric Balance of 6000 Ah, and the 300 Ah from the Battery Features.

$$6000Ah/300Ah = 20Batteries$$

Equation 2. *Calculations established by the author.*

The twenty batteries would be divided into ten Battery Banks of two 12V:300 Ah batteries in series, along with the six Quattros, creating a whole 24V DC-grid of 6000 Ah.

$$2BatterisOf12V300AhInSeries = 1BatteryBankOf600Ah$$

$$10BatteryBanksOf24V600AhInParallel = 1StorageSystemOf24V6000Ah$$

Equation 3 & 4. *Calculations established by the author.*

The previous equations are the steps used to calculated the following table of contest.

Calculations Battery Bank	Number of Batteries	Battery Voltage	Number of Batteries in Series	Number of Batteries in Parallel	Battery Capacity (Amph)	Total Batteries In Series AmpH.	Total AmpH Storage System
Units	N	V	N	N	Ah	Ah	Ah
Values	20	12	2	10	300	600	6000

Table 2. *Calculations of the Battery Banks for Designing the Storage System. Table by the author.*

The values exposed on *"Table 2, Calculations of the Battery Banks for Designing the Storage System"* are the final results of the calculations to establish the Storage Systems of the Installation on board the schooner.

3. PROJECT SPECIFICATIONS & BLUEPRINTS

3.1. Tables of Contest of the Electric Balances

a) Table of Contents of the Electric Balance of the Total Power Installed on board

	Load Type	*Number of Units*	*Power Installed*	*Total Power Installed*	*Utilisation Factor*	*Total Absorbed Power (P)*	*Power Factor*	*Total Reactive Power (Q)*	*Total Apparent Power (S)*
Receiver	***Phase***	***Total***	***kW***	***kW***	***Ku***	***kW***	***cos(ϕ)***	***kVAr***	***kVA***
Fire Protection Pump	*Three-Phase*	1	1,1	1,1	0,8	0,88	0,8	0,66	1,1
Bilge Pump	*Three-Phase*	1	1,5	1,5	0,8	1,2	0,8	0,9	1,5
Hundested Cooling Pump	*Three-Phase*	1	1,1	1,1	0,8	0,88	0,8	0,66	1,1
D.O. Transfer Pump	*Three-Phase*	1	1,1	1,1	0,8	0,88	0,8	0,66	1,1
Sea Water Pump	*Three-Phase*	2	1,5	3	0,8	2,4	0,8	1,8	3
Centrifuge Separator (Alfa Laval)	*Mono-Phase*	1	2,2	2,2	0,8	1,76	0,8	1,32	2,2
Ballast Pump	*Three-Phase*	1	1.5	1,5	0,8	1,2	0,8	0,9	1,5
Air Compressor	*Mono-Phase*	3	1,5	4,5	0,8	3,6	0,8	2,7	4,5
Aircon. S.W. Pump	*Three-Phase*	1	1,1	1,1	0,8	0,88	0,8	0,66	1,1
Aircon. Circu. Pump	*Three-Phase*	1	1,1	1,1	0,8	0,88	0,8	0,66	1,1
Electric Boilers.	*Three-Phase*	3	1,5	4,5	0,8	3,6	0,8	2,7	4,5
Circulation Fans	*Mono-Phase*				0,8		0,8	0	0

	Load Type	Number of Units	Power Installed	Total Power Installed	Utilisation Factor	Total Absorbed Power (P)	Power Factor	Total Reactive Power (Q)	Total Apparent Power (S)
Shore Power Converter Cooling Pump	Three-Phase	1	1,1	1,1	0,8	0,88	0,8	0,66	1,1
Enginero om intake & Extra. Fan	Three-Phase	2	1,1	2,2	0,8	1,76	0,8	1,32	2,2
L.P. Watermak er Pump	Three-Phase	2	1,1	2,2	0,8	1,76	0,8	1,32	2,2
H.P. Watermak er Pump	Three-Phase	2	3	6	0,8	4,8	0,8	3,6	6
Freash Water Pump	Three-Phase	2	1,1	2,2	0,8	1,76	0,8	1,32	2,2
Sewage Treatment	Three-Phase	1	2	2	0,8	1,6	0,8	1,2	2
Grey Water Pump	Three-Phase	1	1,1	1,2	0,85	1,02	0,850	0,632	1,200
Black Water Pump	Three-Phase	1	1,1	1,2	0,85	1,02	0,850	0,632	1,200
Cook Top	Three-Phase	1	2	2	0,75	1,5	0,75	1,323	2
Oven	Three-Phase	1	2,2	2,2	0,8	1,76	0,8	1,32	2,2
Dishwash er	Three-Phase	1	2	2	0,8	1,6	0,8	1,2	2
Microwav e	Mono-Phase	1	1,1	1,1	0,8	0,88	0,8	0,66	1,1
Washing machine	Three-Phase	1	1,5	1,5	0,6	0,9	0,8	0,675	1,125
Steering Pump	Three-Phase	1	3	3	0,8	2,4	0,8	1,8	3
Electric Winches	Three-Phase	8	2,2	17,6	0,76	13,376	0,76	11,439	17,6
Dryer	Three-Phase	1	3,5	3,5	0,9	3,15	0,9	1,526	3,5

	Load Type	Number of Units	Power Installed	Total Power Installed	Utilisation Factor	Total Absorbed Power (P)	Power Factor	Total Reactive Power (Q)	Total Apparent Power (S)
Bowthruster	Three-Phase	1	75	75	0,82	61,5	0,82	42,927	75
Windlass	Three-Phase	1	11	11	0,7	7,7	0,7	7,856	11
Navigation Lights + Instruments	Mono-Phase	50	0,1	5	1	5	1	0	5
Guests Lights	Mono-Phase	35	0,1	3,5	1	3,5	1	0	3,5
Crew Lights	Mono-Phase	25	0,1	2,5	1	2,5	1	0	2,5
Engine Room Lights	Mono-Phase	30	0,1	3	1	3	1	0	3
Total Installation Power		185	129,2	173,7	0,819	141,526	0,824	95,029	173,325

Table 1. *Electric Balance of the Total Power Installed on board. Table by the author.*

b) Table of Contest of the Electric Balance of the Operation of the Navigation Loads

	Load Type	Number of Units	Power Installed	Total Power Installed	Util. Factor	Absorbed Power (P)	Power Factor	Reactive Power (*Q*)	Apparent Power (*S*)	Power Used Sailing
Recei-ver	**Phase**	**Total**	**kW**	**kW**	**Ku**	**kW**	**cos(ϕ)**	**kVAr**	**kVA**	**Kw**
Winch Star board Mizzen sheet	Three-Phase	1	2,2	2,2	0,2	0,44	0,76	0,376	0,579	1,672
Winch Port Mizzen sheet	Three-Phase	1	2,2	2,2	0,2	0,44	0,76	0,376	0,579	1,672
Winch Star board Mains heet	Three-Phase	1	2,2	2,2	0,2	0,44	0,76	0,376	0,579	1,672
Winch Port Mains heet	Three-Phase	1	2,2	2,2	0,2	0,44	0,76	0,376	0,579	1,672
Winch Star board Fore sheet	Three-Phase	1	2,2	2,2	0,2	0,44	0,76	0,376	0,579	1,672
Winch Port Fore sheet	Three-Phase	1	2,2	2,2	0,2	0,44	0,76	0,376	0,579	1,672
Hydr. Steering Pump	Three-Phase	1	2,2	2,2	0,76	1,672	0,76	1,430	2,200	1,672
Fire/ Bilge Pump	Three-Phase	1	1.5	1,5	0,8	1,2	0,8	0,900	1,500	0
D.O. Transfer Pump	Three-Phase	2	1,1	2,2	0,8	1,76	0,8	1,320	2,200	0
Hundes-ted Refrige ration & Hydr. Pump	Three-Phase	1	1,1	1,1	0,8	0,88	0,8	0,660	1,100	0

	Load Type	Number of Units	Power Installed	Total Power Installed	Util. Factor	Absorbed Power (P)	Power Factor	Reactive Power (*Q*)	Apparent Power (*S*)	Power Used Sailing
Ballast Pump	Three-Phase	1	1.5	1,5	0,8	1,2	0,8	0,900	1,500	1,2
Nav. Lights + Instruments	Mono-Phase	50	0,1	5	1	5	1	0,000	5,000	5
Engine Room Lights	Mono-Phase	30	0,1	3	1	3	1	0,000	3,000	
Engine room intake & Extra. Fan	Three-Phase	2	1,1	2,2	0,8	1,76	0,8	1,320	2,200	0
L.P. Water maker Pump	Three-Phase	2	1,1	2,2	0,8	1,76	0,8	1,320	2,200	0
H.P. Water maker Pump	Three-Phase	2	3	6	0,8	4,8	0,8	3,600	6,000	0
Total Installation Power		98	23	40,1	0,637	25,672	0,808	18,753	31,792	17,904

***Table 2.** Electric Balance of the Operation of the Navigation Loads. Table by the author.*

c) Table of Contest of the Electric Balance of the Manoeuvring Loads

	Load Type	Number of Units	Power Installed	Total Power Installed	Utilisation Factor	Total Absorbed Power (P)	Power Factor	Total Reactive Power (Q)	Total Apparent Power (S)
Receiver	**Phase**	**Total**	**kW**	**kW**	**Ku**	**kW**	**cos(ϕ)**	**kVAr**	**kVA**
Windlass	Three-Phase	1	11	11	0,7	7,7	0,7	7,856	11,000
Bow-thruster	Three-Phase	1	75	75	0,82	61,5	0,82	42,927	75,000
Hydraulics Steering Pump	Three-Phase	1	2,2	2,2	0,76	1,672	0,76	1,430	2,200
Nav. Lights + Instru-ments	Mono-Phase	50	0,1	5	1	5	1	0,000	5,000
Total Average Winches	Three-Phase	6	2,2	13,2	0,2	2,64	0,76	2,258	3,474
Engine Room Lights	Mono-Phase	30	0,1	3	1	3	1	0,000	3,000
Total Installation Power		89	90,6	109,4	0,896	81,512	0,840	54,470	97,038

Table 3. *Electric Balance of the Manoeuvring Loads. Table by the author.*

d) Table of Contest of the Electric Balance of the Extra Loads.

	Load Type	Number of Units	Power Installed	Total Power Installed	Utilisation Factor	Total Absorbed Power (P)	Power Factor	Total Reactive Power (Q)	Total Apparent Power (S)
Receiver	**Phase**	**Total**	**kW**	**kW**	**Ku**	**kW**	**cos(ϕ)**	**kVar**	**kVa**
Air Compressor	Mono-Phase	3	1,5	4,5	0,8	3,6	0,8	2,700	4,5
Aircon. S.W. Pump	Three-Phase	1	1,1	1,1	0,8	0,88	0,8	0,660	1,1
Aircon. Circu. Pump	Three-Phase	1	1,1	1,1	0,8	0,88	0,8	0,660	1,1
Electric Boilers.	Three-Phase	3	1,5	4,5	0,8	3,6	0,8	2,700	4,5
Circulation Fans	Mono-Phase	2	1,1	2,2	0,8	1,76	0,8	1,320	2,2
L.P. Water maker Pump	Three-Phase	2	1,1	2,2	0,8	1,76	0,8	1,320	2,2
H.P. Water maker Pump	Three-Phase	2	3	6	0,8	4,8	0,8	3,600	6
Freash Water Pump	Three-Phase	2	1,1	2,2	0,8	1,76	0,8	1,320	2,2
Sewage Treatment	Three-Phase	1	2	2	0,8	1,6	0,8	1,200	2
Cook Top	Three-Phase	1	2	2	0,75	1,5	0,75	1,323	2
Oven	Three-Phase	1	2,2	2,2	0,8	1,76	0,8	1,320	2,2
Dish-washer	Three-Phase	1	2	2	0,8	1,6	0,8	1,200	2
Micro-wave	Mono-Phase	1	1,1	1,1	0,8	0,88	0,8	0,660	1,1

	Load Type	Number of Units	Power Installed	Total Power Installed	Utilisation Factor	Total Absorbed Power (P)	Power Factor	Total Reactive Power (Q)	Total Apparent Power (S)
Washing machine	Three-Phase	1	1,5	1,5	0,6	0,9	0,8	0,675	1,125
Dryer	Three-Phase	1	3,5	3,5	0,9	3,15	0,9	1,526	3,5
Guests Lights	Mono-Phase	35	0,1	3,5	1	3,5	1	0,000	3,5
Crew Lights	Mono-Phase	25	0,1	2,5	1	2,5	1	0,000	2,5
Total Installation Power		83	26	44,1	0,815	36,43	0,826	22,183	43,725

Table 4. *Total Power Installed by the Extra Loads. Table by the author.*

e) Table of Contest of the Electric Balance of Shore Connection Loads

	Load Type	Number of Units	Power Installed	Total Power Installed	Utilisation Factor	Total Absorbed Power (P)	Power Factor	Total Reactive Power (Q)	Total Apparent Power (S)
Receiver	**Phase**	**Total**	**kW**	**kW**	**Ku**	**kW**	**cos(ϕ)**	**kVar**	**kVa**
Shore Power Converter Cooling Pump	Three-Phase	1	1,1	1,1	0,8	0,88	0,8	0,66	1,1
Extra Daily Loads	Mono & Three-Phase	23	25,8	38,1	0,790	30,43	0,803	22,585	37,895
Total Installation Power		24	26,9	39,2	0,795	31,31	0,802	23,245	38,995

Table 5. *Total Power Installed for Shore Connections. Table by the author.*

f) Table of Contest of the Electric Balance of the DC & AC Grid of the Storage System

	Num. of Units	Voltage	Current	Absorbed Power/ Unit	Total Absorbed Power	Number of Daily Used Hours	Watts Hour/ Day	Amp.Hour/ Day	Watts Hour	Amp. Hour	Total Power & 50 % Margin of Dis-charge	Amp.Hour/ Day & 50% Margin of Dis-charge
Receiver	Total	V	A	W	W	Hours (h)	Wh/ Day	Ah/ Day	Wh	Hours (h)	(Wh/ Day)	(Ah/ Day)
Radar HD TXL-10S-6	1	24	9,625	230	231	12	2772	116	115,50	4,813	5544	231
Elect. diaphragm pump EMP140B (Grey and Black Pump)	2	24	5	120	240	2	480	20	20	0,833	960	40
Electric centrifugal Fresh Water Pump	1	24	5	120	120	3	360	15	15	0,625	720	30
Elec. toilets - TMWQ	6	24	15	360	2160	0,5	1080	45	45	1,875	2160	90
Lights Engine Room	20	24	0,833	20	400	24	9600	400	400	16,667	19200	800
Crew Lights	20	24	0,833	20	400	8	3200	133	133	5,556	6400	267
Guest Lights	25	24	0,833	20	500	8	4000	167	167	6,944	8000	333
Battery Devices	45	24	2,708	65	2925	3	8775	366	366	15,234	17550	731
Navigation Lights + Instruments	40	24	2,708	65	2600	12	31200	1300	1300	54,167	62400	2600
Refrigerators	6	24	5,000	120	720	8	5760	240	240	10,000	11520	480

	Num. of Units	Voltage	Current	Absorbed Power/ Unit	Total Absorbed Power	Number of Daily Used Hours	Watts Hour/ Day	Amp.Hour/ Day	Watts Hour	Amp. Hour	Total Power & 50 % Margin of Dis-charge	Amp.Hour/ Day & 50% Margin of Dis-charge
Extra AC daily Loads	6	240	0,833	200	1200	2	2400	10	100	0,417	4800	20
Total Values	172	24 or 240	48,375	1340,00	11496	82,5	69627	2811	2901,13	117,130	139254	5802

Table 6. *24 & 240 V Storage System Electric Balance. Table by the author.*

g) Table of Contests of the Electric Balance of the Hydrogenation System Generated Power

Type	Number Of PODs	Total Continues Power	Total Amps/ Hour	75% Of Power Efficiency	Total Power During 24h	Total A.Hour during 24h	Total Power During a Year (144 days)	Total A.Hour/ Year
Units	**N**	**kW**	**Ah**	**kW**	**kW**	**Ah/Day**	**kW/year**	**Ah/Year**
PMSM	2	20	220	15	360	5280	51840	760320

Table 7. *Hydrogenation System Total Generated Power. Table by the author.*

4. CONCLUSION

4.1. Total Hydrogenation System, Storage & Distribution System final Budget

The Final Budget, which shows the efficiency, and the amortisation of the installation is divided into the total storage system, and the hydrogenerators expenses including the indirect expenses, and the total energy generated by the hydrogenation system, during a period of durability of the installation of 10 years. This values are compared, to how much that energy would have had cost instead, if it was generated by the diesel generators, plus the amount of expenses saved in maintenance, and also the increase of the life time of the diesel generators.

First of all the budget is composed by the equipment to install and the raw materials which are used in the construction of the installation.

The following contest table "*Table 1, Equipment & Raw installation materials budget*" exposes the total expenses of the raw materials, which composes the total coast of the storage, and the hydrogenerators installations.

Equipment & Raw Materials Budget			
Type	**Number of Units**	**Price By Unit**	**Total Price**
Units	**N**	**Euros**	**Euros**
LBP12V300Ah	20	2.818,80	56376
Arka POD 10kW	2	3000	6000
Quattro	6	3735,51	22413,06
Circuit Breakers + Diferential switches	10	199,468	1994,68
Fuses	40	46,822	1872,88
Wiring (per meter)	200	5	1000
Total Result	278	9805,6	**89656,62**

Table 1. *Equipment & Raw installation materials budget. Table by the author.*

The next step of the budget is to introduce the cost of the labor force, which is composed of external workers to the ship which have worked on the installation supervised by the Chief Engineer and the captain.

Labor Force	Hours	Price/Hour	Total cost
Electrical Engineer	10	90	900
Electronic Engineer	8	90	720
Naval Engineer	8	90	720
Electrical technician 1	24	45	1080
Electrical technician 2	24	45	1080
Total Labor Force Costs			4500

Table 2. *Labor Force total budget. Table by the author.*

After acquiring the main budgets of the costs of the installation it is expendable to add the total indirect costs, which consists of general costs, licenses and administration paperwork that are a 10 % of the total sum of the equipment & raw materials, plus the labor force budget. Another two indirect costs are the project fees, which consists of the 5 %, and the national taxes (IVA), which is the 21 %. The Final Total budget would be the sum of the total direct costs and indirect costs. These final budget calculations are exposed on the next page at the table of contest "*Table 3. Total Final Budget of the installation*".

FINAL TOTAL BUDGET	
Equipment & Raw Materials Budget	89656,62
Labor Force	4500
Total Costs Equipment & Raw Materials + Labor Force	**94156,62**
INDIRECT COSTS	
General costs licenses & paperwork (10 %)	9415,66
Project fees (5 %)	4707,83
National Taxes or IVA (21 %)	19772,89
Total Indirect Costs	**33896,38**
Total Final Budget Costs	**128053**

Table 3. *Total Final Budget of the installation. Table by the author.*

The total cost consumption of the diesel generators per kW/h from the installation is exposed on the following contest table "*Table 4, Diesel Generator Consumption & Expenses*".

GENERATOR DATA							
Type	**Total Generated Power**	**80 % Generated Power**	**Total Synchronised Power**	**Generators Fuel Consumption**	**Fuel Price per ltr**	**Price kW/h**	**Total Price per kW/h Generated**
Units	**kW**	**kW/h**	**kW**	**ltr/h**	**Euros**	**Euros**	**Euros**
M1066T	80	64	156	24	1	0,375	24
M1066A2	115	92	156	35,2	1	0,383	35,200

Table 4. *Diesel Generator Consumption & Expenses. Table by by the author.*

The average of both diesel generators price per kW/h generated is exposed in the next contest table "*Table 5, Total Average Price Per kW/h & Total Maximum Generated Power Price per Hour*".

Total Max. Synchronised Power	Average Price Per kW/h	Total Price per Total Max. Power Generated / Hour
kW	**Euros**	**Euros**
156	0,379	59,124

Table 5. *Total Average Price Per kW/h & Total Maximum Generated Power Price per Hour. Table by the author.*

The total energy generated by the hydrogenerators during a period of 10 years, when compared to the value of the amount of energy if it was generated by the diesel generators, it gives the total value of the economic benefits generated, exposed on the table "*Table 6. Total Power & Economic gains during a period of 10 years*".

Type	Number Of PODs	Total Continues Power	Total Amps/ Hour	75% Of Power Efficiency	Total Power During 24h	Total A.Hour during 24h	Total Power During a Year (144 days)	Total A.Hour/ Year
Units	**N**	**kW**	**Ah**	**kW**	**kW**	**Ah/Day**	**kW/year**	**Ah/Year**
PMSM	2	20	440	15	360	10560	51840	1520640
Average Price Per kW/h	**Total Power during 10 Year by PODs**	**Total Money in Energy Generated by PODs**						
Euros	**kW**	**Euros**						
0,379	518400	196473,60						

Table 6. *Total Power & Economic gains during a period of 10 years. Table by the author.*

To acquire the total value of expenses savings, it is needed to included the total number of working hours equivalent if that energy was being generated by the diesel generators. With that amount of diesel generator working hours, it is posible to achieve the total equivalent maintenances expenses.

Total Equivalent Running Hours of the Diesel Generators	Every 500 hours the Oil & Oil filters must be maintained.	Also Extra Maintenance like Anodes, Impellers, belts, etc.	Total Maintenance Coast	Total Money in Energy Generated by the Hydro-Generators	Total Storage & Hydrogenation Installations Expenses
h	**Euros**	**Euros**	**Euros**	**Euros**	Euros
3323,077	5500	4500	10000	196473,60	128053

Table 5. *Total Benefits & Expenses of the Installation. Table by the author.*

The total result of adding the benefits, and subtracting the total expenses of the installation, which gives us the total result of the 10 year period benefits, it is exposed in the following equation.

$$(TotalMaintananceCoast) + (TotalPODsBenefits) - (InstallationsExpenses) = TotalInstallationsBenefits$$

$$10000 + 196473{,}60 - 128053 = 78420{,}60 Euros$$

Equations 1. *Calculations by the author.*

If the total benefits are divided by 10, the average benefits per year are acquired. With that value it is possible to obtain, how long would it take for the installations to pay its expenses (period of time to breakeven). This process is expose in the continues equations.

$$TotalBenefits/Total10Years = (10000 + 196473{,}6)/10 = 20647{,}36Euros/Year$$
$$128053/20647{,}36 = 6{,}2Years$$

Equations 2. *Calculations by the author.*

After a period of 6,2 years, the hydrogenerators, and the storage system would have payed it self (breakeven), and after that period of time, all the generated power it will become into economic profits.

4.2. Conclusion of the technical study

The ambition of this technical study, is to expose the impact of adding a proper optimised hydrogenation and storage system, correctly distributed throughout the installation of a schooner. And how the results of those implementations are reflected into the generated plant, increasing the efficiency of the installations, reducing its fuel consumption, its working hours, its maintenance and with it increasing the life time of the diesel generators, creating economic and environmental benefits, established by the reduction of costs, emissions and wastes of the generating plant of the schooner.

The Battery & the Quattro Systems, must be highlighted because of its great performance for the constant energy storage of the clean energy generated by the hydrogenation systems, and by their capability of absorbing the extra energy generated by the generators, and as well for being able to distribute that energy whenever is most needed.

As is reflected on the section "*4.1. Total Hydrogenation System, Storage & Distribution System final Budget*", to be able to amortise the expenses of this installation, the schooner must constantly sail a great amount of hours, during a big period of time of minimum 6,2 years to just breakeven. In the economical aspect to make this type of installation profitable you must have a long time sailing period expectation, like a round the world trip itinerary, and even through that kind of trip, to be able to sail that amount of time, throughout such a long period of time, is really hard, and not possible for most of the normal sailing vessels. Which gives us the conclusion that is really hard to make this whole installation worth it in the economical aspect, if you are not looking forward to sail everyday for al least the next 10 years.

But if we look at this project as the environmental benefits that creates, it is a complete gain. The installation of the hydrogenerators, and the designe of the optimise storage system decreases the pollution generated by the schooner in quite a few brunches. First of all the amount of emission emitted by the diesel generators are decreased, but also their amount of oil consumption, their number of used filters, and as well as other extra maintenance expenses like anodes and timing belt have been reduced, decreasing the amount of waste of the installation of the schooner.

Another benefit of the installation is that the same concept of the Hydrogenation System can be applied, with any other renewable energy, like Solar-Panels or Wind Turbines. Anyone of those exposed systems can be chosen, and implemented to fit as good as possible into the stablished installation, if we apply it with the specific installations requirements of each device. If extra renewable energies are implement into the system, this would reduce the economic amortisation period and would increase even more the efficiency of the installation, and throughout a clean energy resource.

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