CHALMERS

Design of a fuel cell system

Design of a specification of requirements for a fuel cell system for the electric power generation in a 77-foot sailing ship

Master of Science Thesis

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Göteborg, Sweden, 2007

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Cover:
The picture on the cover features T/S Prolific. More information about T/S Prolific can be found in the report.

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Abstract

The idea for this thesis was to design a specification of requirements for a fuel cell system for the electric power production in a 77-foot sailing ship named T/S Prolific. The fuel cells are intended to complement the existing diesel generator, which is used to deliver power to the three phase system and to charge the batteries used for the low voltage applications. The initiative to the project was first taken by Hydrogen Sweden, a non-profit association which has the goal of promoting the use of hydrogen in Sweden.

In a fuel cell a reaction takes place where hydrogen and oxygen recombine into water and thereby releasing energy. A cell consists of two electrodes, anode and cathode, with a layer of electrolyte between them. Hydrogen is supplied to the anode and oxygen to the cathode. The reaction in the fuel cell generates electrons which form a current that flows from the anode to the cathode via an external circuit.

In order to design the specification of requirements, parameters such as consumed power, voltage and current were measured during one month of sailing. The measured data was then studied and analyzed to achieve a value of the power rating for the new system. Calculations for the volume needed to store the fuel were performed based on the desired running time of the fuel cells. A control system, based on power electronics, to integrate the fuel cells and the generator into a hybrid system were thought of.

The fuel cell system that has been studied for T/S Prolific is intended to be silent rather than environmentally benign. This system should be capable of delivering the needed energy during night sailing and for some periods during the day and therefore the power rate was chosen to be 2.5 kW. The cells used in this project will use hydrogen as fuel and the storage was designed to hold enough hydrogen for two days at sea. This amount was calculated to be 1.52 kg which is equivalent to a volume of 100 dm^3 at a pressure of 200 bar. The placement of the entire fuel cell system is intended to be above deck to minimize the risk of accidents.

This thesis is intended to be a foundation for the design and installation of a fuel cell system in T/S Prolific. The results of the analysis are presented in a specification of requirements table to function as a foundation for the decision-makers and suppliers. These specifications are based solely on technical aspects, and the economical part is up to the decision-makers and suppliers to look into.

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Definitions and abbreviations

PEM	Proton Exchange Membrane
CHP	Combined Heat and Power
BOP	Balance of Plant
DC	Direct Current
AC	Alternate Current
P	Power
W	Watt
E	Energy
E_{H_2}	Energy content in one kilogram of hydrogen gas
Wh	Watt hour
LHV	Low Heating Value
V	Voltage, Volts
I	Current
A	Ampere, Area
Ah	Ampere hour
J	Current density, Joule
m	Mass
kg	Kilogram
Hz	Hertz
H_2	Hydrogen gas
O_2	Oxygen

H^+	Proton
OH^-	Hydroxil ions
H_2O	Water
CO_2	Carbon dioxide
DSP	Digital Signal Processor
PP	PowerProfile
PC	Personal Computer
PV	Photovoltaic
LPG	Liquefied Petroleum Gas

1 INTRODUCTION

The development in the world today is contributing to major emissions of green house gases. This has lead to debates on how to make the manufacturing processes and the technology more environmentally benign. Thoughts like these have inspired several actors to search for innovative solutions with new technology. The objective of this thesis is to design a specification of requirements for a fuel cell system which should complement the diesel generator with the electrical power production in a ship. Diesel generators are at this moment the best way to generate power in ships but other energy sources such as wind and solar power could be used as a complement. The reasons for using fuel cells are that it is environmentally benign, that the noise from power generation is less than for the conventional method and that there are no exhaust gases from the system. In this thesis the priority is mainly on the latter two and the environmental issue comes in second.

The initiative force behind this project is Hydrogen Sweden, a non-profit association with the goal of promoting the use of hydrogen in Sweden. To achieve this purpose, Hydrogen Sweden cooperates with different partners such as legislators, industries, universities and research institutes.

Studies on the use of fuel cells in large ships have been performed in cooperation between several actors. Unfortunately the results were negative due to that fuel cells were not economically competitive compared to the existing technology and that there is no available infrastructure for hydrogen [14]. Therefore the attention is focused on smaller ships. The ship used in this study is a 77-foot sailing ship named T/S Prolific, used for educational purposes at “Maritima gymnasiet” high school, located at Orust on the west coast of Sweden.

The objective of the thesis is not about designing the fuel cell system but to function as a foundation for future decisions regarding the investment in the equipment. The goal is to achieve a specification of requirements for the system. This specification is based on measurements of the consumed power in the ship.

The thesis is divided into different sections starting with a description of the method used during the thesis work. A chapter about fuel cells follows and then a short description of T/S Prolific and its electrical system is given. A chapter concerning the measurement equipment, installation and the measurements follows thereafter. The next part is a basic description of a fuel cell system and after that, thoughts about additional power production is presented. Then a description on hybrid systems for the ship and the specification of requirements for the fuel cell system is given. Finally the thesis is ended with a discussion and conclusion chapter.

2 METHOD

The procedure used during the thesis work was made up of measurements, analysis and design. In the approach to the measurements the first thing that had to be done was to decide which parameters that were interesting for this study. The power was decided to be the most useful parameter because of its importance when deciding the power rate and the physical size of the fuel cell system. Voltage and current were measured for the three phases at the output of the diesel generator in order to calculate the power. The total power consumption in the ship is delivered by the generator and therefore it is sufficient to measure the generator output.

The measurements were performed by installing a measurement device, Unilyzer 901, capable of storing information for a long time period depending on the sampling interval. The instrument collected data during one month sailing and the data was regularly downloaded. The first days, the downloads were performed on board to ensure that the instrument functioned as planned and to get an overview of the possibilities of installing fuel cells in the ship. After that, the transfer of data was made via modem.

When all data had been collected the analysis could be started. The power was studied for the entire trip to get an overview of the behavior and to map different power levels. This was further analyzed by arranging it in tables and diagrams to get a better understanding of the power consumption. These arrangements were made in Microsoft Excel which was used for most of the analysis. From these studies, different scenarios for the power rate and the quantity of fuel were thought of.

The goal with the thesis was to design a specification of requirements containing parameters such as power rate and the type and quantity of fuel. From the studies of the power consumption the power rate was decided based on the different levels of the power and the time of use. The cost and the size of the system were also kept in mind when the design was carried out. After deciding the type of fuel, the quantity was calculated using the energy content of the fuel and the number of days at sea. The specification of requirements was presented in a table which will be used as a foundation for future decisions concerning the fuel cell system.

3 FUEL CELLS

The first fuel cell was demonstrated in the middle of the 19th century by a scientist named William Grove. In a fuel cell a reaction takes place where hydrogen and oxygen recombine into water and thereby releasing electrical energy. The chemical formula of the reaction is seen in equation 1 [1].

$$2H_2 + O_2 \quad \rightarrow \quad 2H_2O + Energy \tag{1}$$

A fuel cell consists of two electrodes, anode and cathode, with a layer of electrolyte between them, Figure 1. The electrodes are normally made flat and porous to achieve good contact between the electrolyte and the gases. The layer of electrolyte is made thin for the purpose to allow ions to pass through it without too much ohmic losses [1].

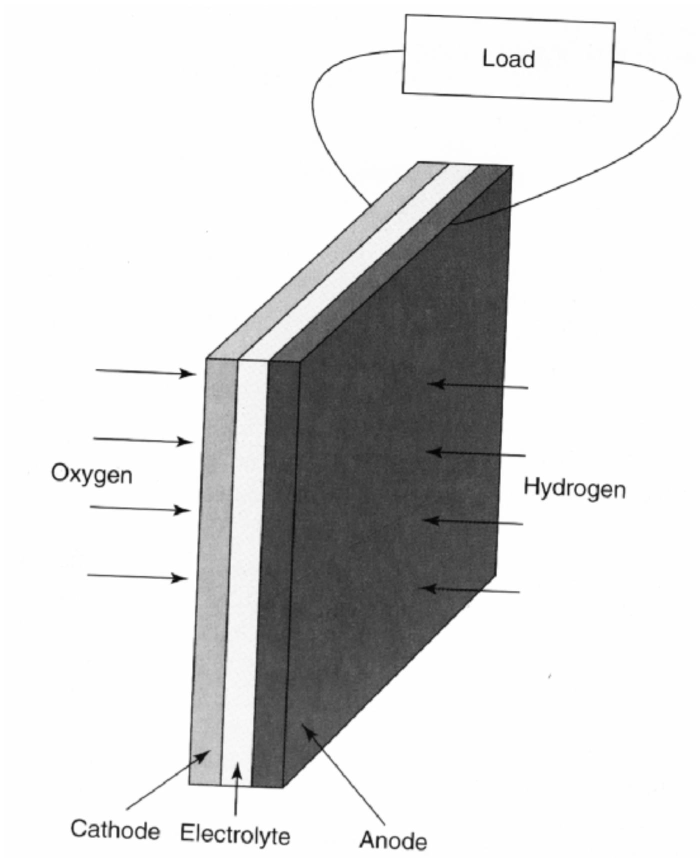


Figure 1. Basic structure of a fuel cell. Courtesy of John Wiley & Sons Limited [P1].

There are many different fuel cell types. The differences between them are the reactions at the electrodes and the electrolyte used. In the following subchapters some of the most common types of fuel cells are explained briefly.

3.1 Acid electrolyte fuel cell

The most common type of fuel cell is the acid electrolyte, seen in Figure 2. At the anode the following reaction takes place [1].

$$2H_2 \quad \rightarrow \quad 4H^+ + 4e^- \tag{2}$$

Hydrogen gas ionizes into hydrogen ions and electrons, equation (2). The electrons released from the reaction flow through an external load to the cathode, creating a current. The H^+ ions pass through the electrolyte which is possible because an acid is a fluid with mobile H^+ ions. At the cathode the H^+ reacts with oxygen and the electrons forming water, equation (3) [1].

$$O_2 + 4e^- + 4H^+ \quad \rightarrow \quad 2H_2O \tag{3}$$

The electrons are not allowed to pass through the electrolyte because then no current would flow in the external circuit. [1].

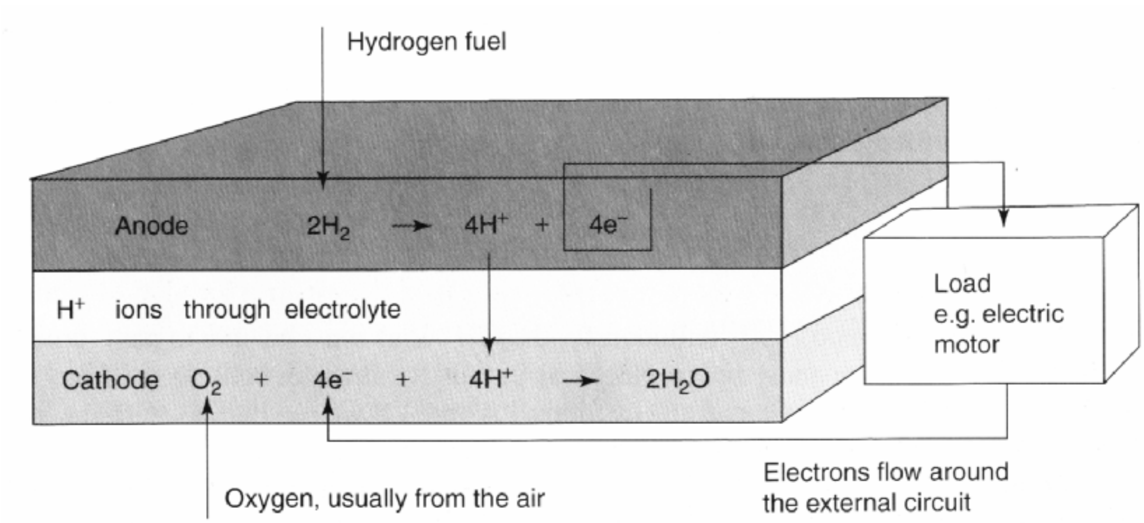


Figure 2. Electrode reactions and electrical flow for an acid electrolyte fuel cell. The electrons flow from the anode to the cathode via an external circuit. Courtesy of John Wiley & Sons Limited [P1].

3.2 Alkaline electrolyte fuel cell

In the Alkaline electrolyte the reaction is similar to the acid electrolyte but the reactions at each electrode are different. In this case the mobile ions are hydroxyl ions (OH^-). The hydrogen fuel reacts with OH^- at the anode producing water and releasing electrical energy, equation (4) [1].

$$2H_2 + 4OH^- \quad \rightarrow \quad 4H_2O + 4e^- \tag{4}$$

At the cathode side the electrons released from the anode reacts with oxygen and water creating new OH^- ions, equation (5). Although water is consumed at the cathode, twice the amount is produced at the anode [1].

$$O_2 + 4e^- + 2H_2O \quad \rightarrow \quad 4OH^- \tag{5}$$

As for the acid electrolyte there must be an external load so that the electrons can flow from the anode to the cathode, Figure 3 [1].

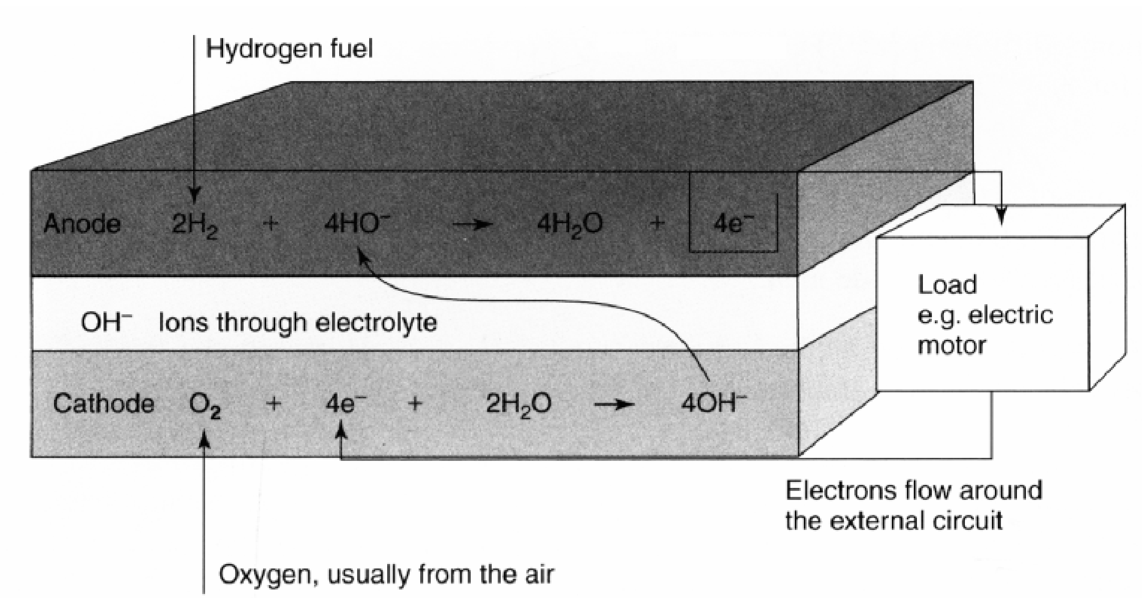


Figure 3. Electrode reactions and electrical flow for an alkaline electrolyte fuel cell. Courtesy of John Wiley & Sons Limited [P1].

Worth mentioning is that for both the acid electrolyte and the alkaline electrolyte twice as many moles of hydrogen as of oxygen are needed in the reaction.

3.3 Proton exchange membrane fuel cell

The Proton Exchange Membrane (PEM) fuel cell is the most useful at present time [6]. A solid polymer, in which protons (H^+) are mobile, is used as electrolyte. The fact that the electrolyte is solid and immobile makes this cell very simple. The working temperature of these cells is quite low, around 30-100°C, which gives a problem of slow reaction rates but at the same time the startup is fast. The problem of slow reaction rates is solved by the use of more effective electrodes and catalysts such as platinum [1]. Another drawback is that the membrane is fragile and breaks easily [6]. The field of application is essentially in vehicles, portable applications and low power CHP (Combined Heat and Power) systems [1].

3.4 Technical and physical description of a fuel cell

Electrical energy is produced when hydrogen reacts at the anode and oxygen at the cathode. To release it, an activation energy must be supplied in order to overcome the energy hill. The reaction has the form shown in Figure 4. If the probability of a molecule having enough energy is low a slow reaction takes place. This is not the case for fuel cell reactions at very high temperatures [1]. To speed up the reaction the most common solutions are:

- Increasing the electrode area
- The use of catalysts
- Raising the temperature

The latter two are applicable to any chemical reaction. The first one is the most important when working with fuel cells. For a reaction like the one in equation (4), fuel gas, OH^- ions and the necessary activation energy are needed. The hydrogen fuel and OH^- ions comes in contact on the surface of the electrode, and at the same time the produced electrons must be removed. The time that this takes is reversed proportional to the area of the electrode, i.e. the larger the electrode area is the less time it takes. The area is such an important issue that the performance of a fuel cell is expressed in ampere/cm^2 [1].

The area of an electrode is not only length × width. The material used is, as mentioned before, made highly porous which gives the benefit of an increased effective surface area. The electrodes in modern fuel cells have a microstructure that makes the effective area hundreds or even thousands times larger than the straightforward area. For practical fuel cells the micro structural design and manufacture of the electrode is an important matter. Other considerations in the design are that catalysts may be added to the material and that the electrode has to withstand high temperatures in a corrosive environment [1]. What counts as a high temperature depends on which type of cells that are used. For a low temperature PEM fuel cell a high temperature is around 80°C [6].

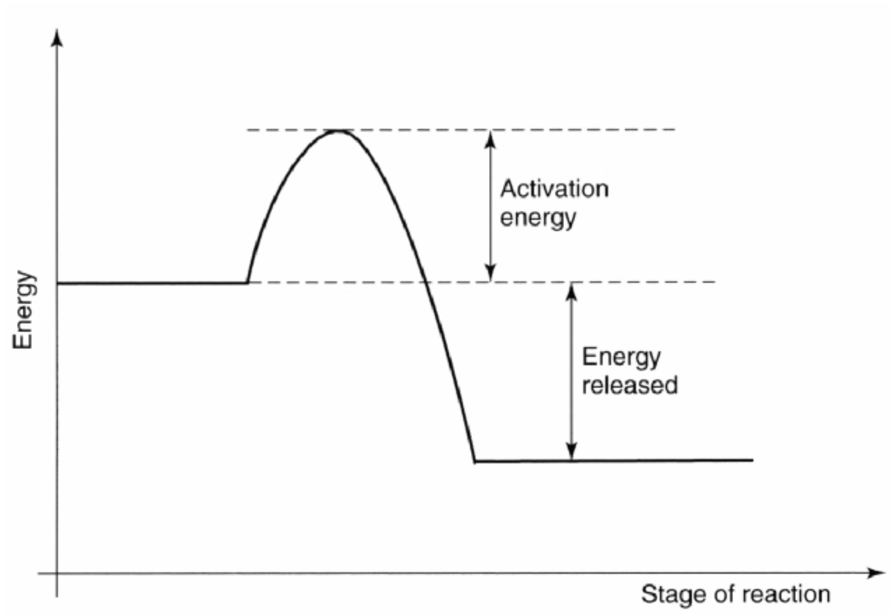


Figure 4. Activation energy diagram for a simple exothermic chemical reaction. Courtesy of John Wiley & Sons Limited [P1].

3.5 Fuel cell stack

3.5.1 Simple series connection

A single fuel cell is made very thin for purposes stated before. This however limits the voltage across it. A typical value for the voltage is about 0.7 V when drawing a useful current. A higher voltage can be achieved by connecting several cells in series which is known as a stack. The easiest way of doing this is to connect the edge of the anode to the cathode of the next cell, Figure 5. With this configuration the electrons have to travel across the surface of the electrode to the edge. Even if the electrodes are good conductors there will be a voltage drop. This drop will be substantial in comparison to the low cell voltage and therefore this method is not used unless the current is very small [1].

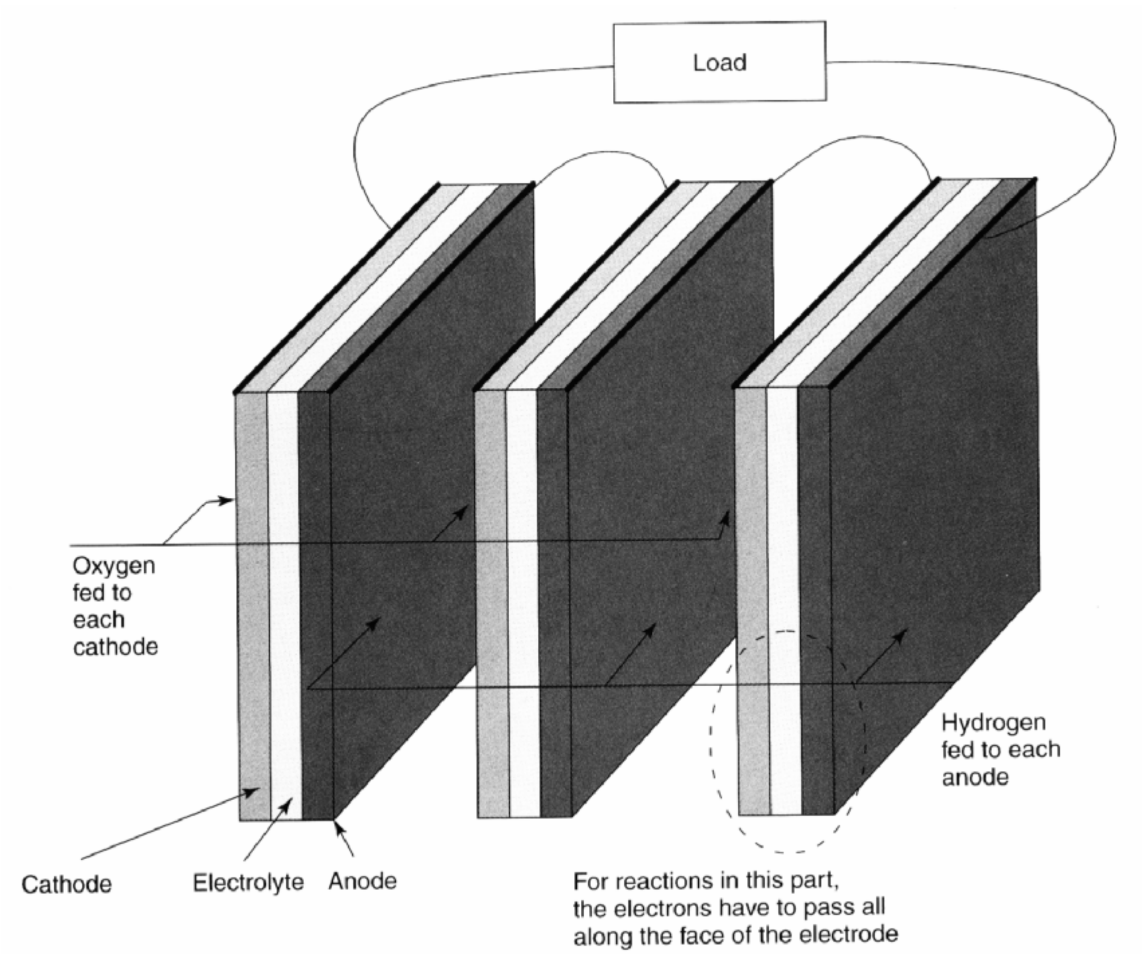


Figure 5. Simple series connection from the anode of one cell to the cathode of the next one. Courtesy of John Wiley & Sons Limited [P1].

3.5.2 Bipolar series connection

A better solution for the construction of a stack is to make the connections with bipolar plates made from materials with good conductivity such as graphite or stainless steel. These plates make connections all over one cathode to the anode of the next cell, hence bipolar. The conditions that they must fulfill are that there has to be a good electric connection between the electrodes and that the different gases must be separated [1].

In the bipolar plates there are normally horizontal channels used to feed oxygen to the cathode and vertical channels to feed hydrogen to the anode, Figure 6. When assembling the stack with bipolar plates a solid block is formed where the current flows more or less straight through the cells instead of across the surface, resulting in better efficiency. The block also becomes more robust and strong due to that the electrodes are better supported. The design of the bipolar plate is somewhat complex where a balance between electrical contact and gas flow has to be considered. If the contact points are made as large as possible optimization of the electrical contact is achieved, but then the gas flow is decreased over the electrodes. Small contact points are also possible but then they should be frequent which makes the manufacturing difficult and expensive as well as a fragile plate. To obtain low resistivity and a small stack size the bipolar plate should be made thin. This results in narrow channels which makes it harder for the gas to flow around the cell [1].

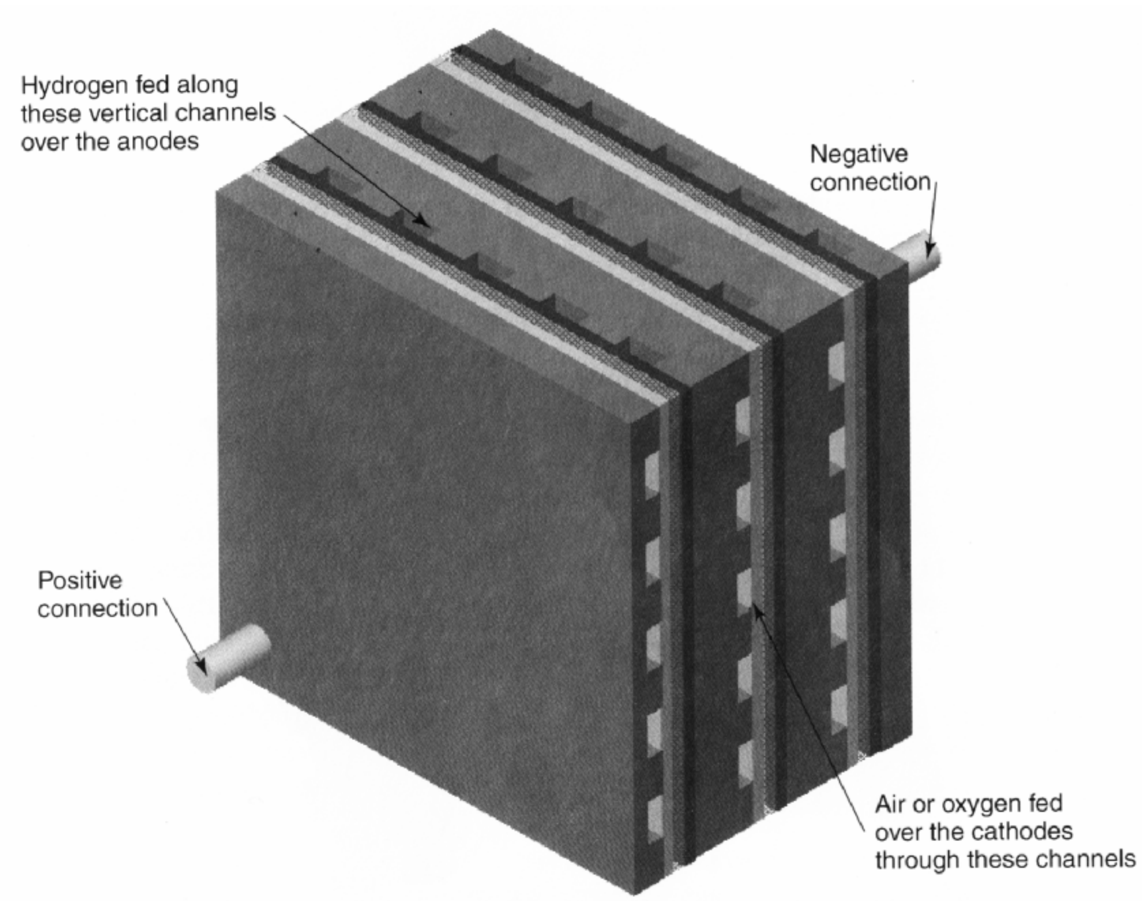


Figure 6. A fuel cell stack, consisting of three cells connected with bipolar plates. Courtesy of John Wiley & Sons Limited [P1].

In reality, when designing a stack with bipolar plates further considerations have to be done. The difficulties include supply and leakage of the gases. As mentioned before the electrodes are made porous to allow the gas to pass through it. A result of this is that the gas can leak out of the edges of the electrodes. The solution to this problem is to seal the edges. This is done by making the electrodes smaller than the electrolyte and then fitting a sealing gasket around them, Figure 7 [1].

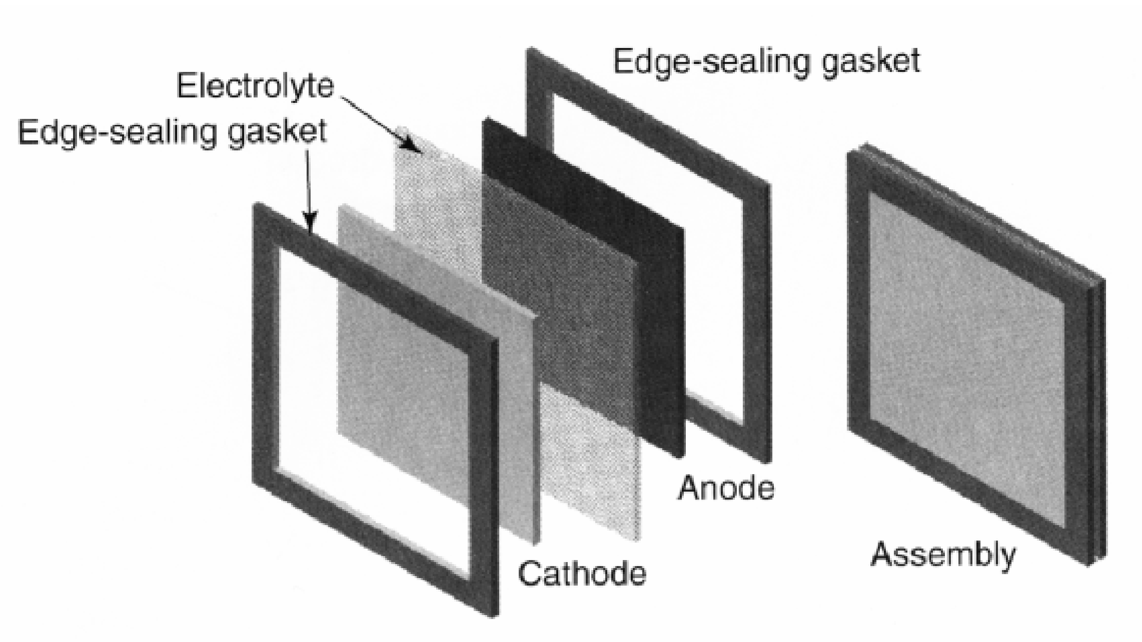


Figure 7. Structure of a fuel cell with edge seals to prevent leakage of the gas at the edges of the electrodes. Courtesy of John Wiley & Sons Limited [P1].

When supplying fuel and oxygen to a fuel cell stack, where the edges of the electrodes are sealed, four manifolds, one at each side, are used. Because of the seals the hydrogen fed vertically only comes in contact with the anodes and the oxygen fed horizontally only comes in contact with the cathodes. The arrangement can be seen in Figure 8, where the manifolds are not assembled. This is called external manifolding and the main advantage is the simplicity of it. However there are two important disadvantages. The first one is the problem regarding the cooling of the system. It is difficult to supply some kind of extra cooling and therefore the cells have to be cooled using the air passing through the cathodes. This leads to that the air has to be supplied at a higher rate than necessary. In some cases this is enough to cool the cells but energy is wasted. The second disadvantage concerns the gasket around the edges of the electrode. At the points where there is a channel it is not pressed down evenly which can cause a leakage of the gases [1].

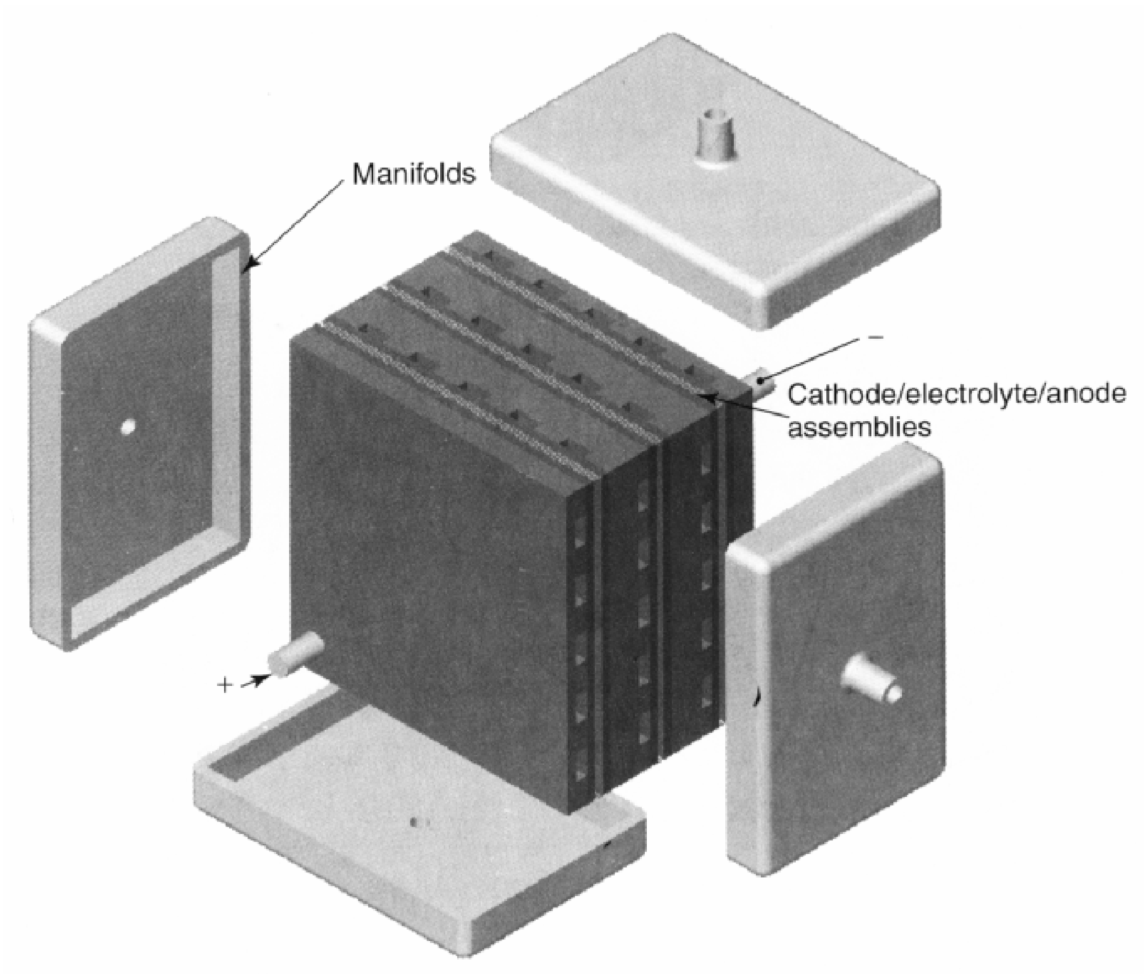


Figure 8. Fuel cell stack with external manifolding. Courtesy of John Wiley & Sons Limited [P1].

A better, yet more complex bipolar plate is made with internal manifolding where the channels are located inside the plate. The plates are also made larger than the electrodes with extra channels running through the stack, as seen in Figure 9. The fuel and the oxygen are fed into the channels via holes placed at each corner of the end plates. A fuel cell stack with internal manifolding has the appearance of a solid block and the gases are fed where the positive and negative connections are made. This arrangement can be cooled in different ways. The easiest way is to drive cooling air or water through the stack by channels at the edges [1].

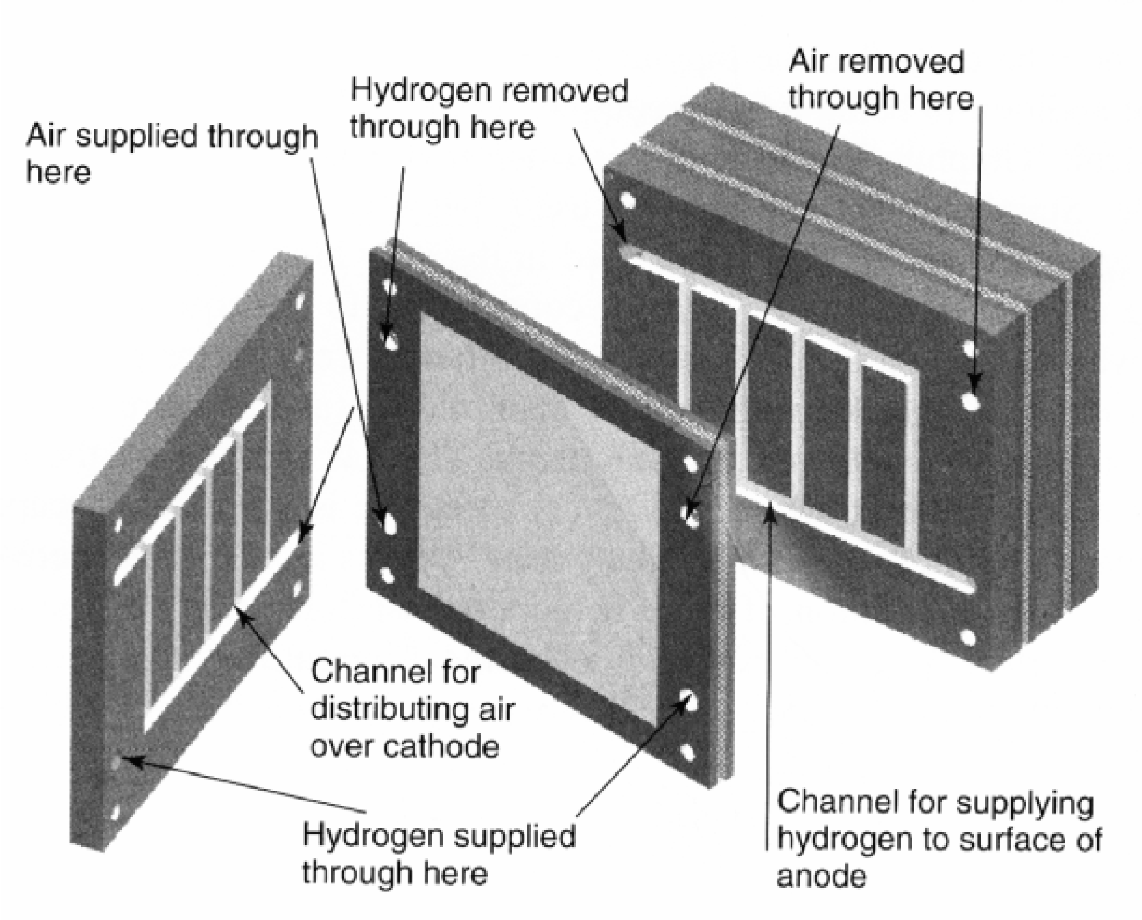


Figure 9. Fuel cell stack with internal manifolding. A more complex bipolar plate is used to allow the reactant gases to be fed to the electrodes through internal channels.
Courtesy of John Wiley & Sons Limited [P1].

3.6 Fuel cell system

In a fuel cell system the stack is the main component but it is only one part of the whole system. The other components are often called the balance of plant (BOP). Elements such as pumps or blowers are used to circulate the air and fuel in the stack. Compressors can be used, sometimes together with intercoolers, as for internal combustion engines. To drive the pumps, blowers and compressors, electric motors are needed [1].

The output of a fuel cell stack is a direct current (DC) which is almost never suitable for direct connection to any load. Therefore some kind of power conditioning is needed. What kind of device that is used depends on the need of the load. It can be a DC/DC converter or a DC/AC inverter [1].

Some kind of fuel storage will always be a part of the system. In the case when the fuel used is not hydrogen a fuel processing system is needed, e.g. to produce hydrogen from fossil fuels [1].

Different control valves, pressure regulators and in most cases a controller for coordination of the system are needed. Start-up and shutdown of the fuel cell system are complex problems for the controller [1].

In larger fuel cell systems a cooling system is necessary. In the case of CHP systems it is called a heat exchanger which takes care of the excess heat and uses it for another application. When using high temperature cells the generated heat is sometimes used in fuel or air pre-heaters. In PEM fuel cells the reactant gases are often humidified [1].

3.7 Energy efficiency, Power and Lifetime

The energy efficiency from a fuel cell stack can be as high as 80%. For the total system the efficiency is lower. How high the efficiency is depends on the amount and what kind of components that are used. For a fuel cell car engine including the whole system, the efficiency from chemical input to kinetic energy is about 30 – 40%. For comparison it should be known that in a conventional internal combustion engine the same efficiency is typically around 18 – 22% [6].

The power drawn by the load is an important aspect for the lifetime of a fuel cell. A smoother power consumption, i.e. an even power outtake without that many peaks, is preferable. This gives a more durable fuel cell. Car engines can be used as an example to illustrate this. A normal internal combustion engine could be assumed to have a lifetime of approximately 5000 hours, in comparison with a fuel cell engine where the lifetime is around 2000 hours. This problem occurs due to the frequent speed variations during car travel as the power consumption rises during the accelerations. If the speed were more or less constant the lifetime could be increased with a factor of 10 to 20 [6]. An application where the fuel cells have better lifetime is in CHP systems of hundreds of kilo watts. In these systems the changes in output power are small which gives a longer lifetime [1].

3.8 Manufacturing and environment

Most people consider fuel cells to be an environmentally benign energy converter. That is true with some modifications. Depending on how the hydrogen fuel is produced the fuel is more or less carbon dioxide (CO_2) free. If it is produced with green electricity, i.e. environmentally benign produced energy from renewable and non-polluting energy sources, the fuel is said to be clean. However, when the production uses electricity from fossil fuels such as coal, oil and natural gas there will be emissions to the atmosphere.

An aspect that is seldom thought of is the manufacture of the cell. The fact that the electrodes and electrolyte are made thin and that the electrode surfaces have a microstructure makes the manufacturing energy demanding. When the cells are bound together into a stack, bipolar plates could be used. These are made from good conducting materials such as graphite or stainless steel [1]. The mining of the raw materials for the plates is energy demanding and gives air pollution and soil contamination [7]. Another environmental problem is that platinum often is used as a catalyst for the electrodes. Platinum is a very scarce metal and when mining, the percentage of pure platinum is very low. This leads to many different processes which are both energy demanding and polluting [16].

3.9 Advantages and Drawbacks

As all technical equipment fuel cells have both advantages and drawbacks. The different drawbacks are more or less important depending on the application and the economy of the project. A short summary of important advantages and drawbacks are listed below.

The advantages are:

- Low emissions
- More efficient compared to a conventional internal combustion engine
- Simplicity, few if any moving parts
- Reliable and long lasting system
- Silent

The drawbacks are:

- Lifetime
- Cost
- Hydrogen has to be produced
- Not yet available infrastructure for hydrogen

4 T/S PROLIFIC

T/S Prolific is a 77-foot sailing ship which was taken into use in 2005. The ship has been sponsored by around 25 companies and is owned by a foundation called Navigare Necesse Est. It is used for educational purposes at "Maritima gymnasiet" high school, located at Orust on the west coast of Sweden and for hiring out to private persons [13]. T/S Prolific can be seen in Figure 10.

Figure 10. T/S Prolific.

The reason for choosing T/S Prolific for this project is the attention it attracts which gives publicity for fuel cells in maritime applications. Many people come in contact with the ship through the school, the sponsors, private persons that rent the ship and via Prolifics webpage. Also, because of its size and that it sails around Sweden and in international waters, it attracts many peoples attention in harbors promoting fuel cells for those interested in boats.

4.1 Existing electrical system

The electrical system in the sailing ship consists of two main parts, the three phase system (400/230 V) and the low voltage (24 V) DC system [10].

There are two different ways to provide electric power to the three phase system. It can be generated by an on board diesel generator (17.5 kW) or by using power directly from land via the shore connection. The latter is possible to use when the ship lies in the harbor. Sometimes there is no possibility for shore connection and in that case the generator delivers the needed power. The three phase system consists of many users. The users with the highest energy demand are the anchor winch (5.5 kW), outlet fan heaters (2×2 kW; 5 kW) and electric oven (3.5 kW).

To deliver the power to the low voltage applications such as navigation equipment, lighting, pumps and winches batteries are used. These consumer batteries are charged via a battery charger, either from the diesel generator or from the shore connection. There is a possibility to use the batteries for the three phase applications by the use of an inverter [10]. This is seldom used due to that the inverter has a limited power.

The motor used for propulsion of the ship is a Volvo Penta that is capable of recharging its own start battery but also to charge the consumer batteries [10].

The electrical schematic of the sailing ship that was used to describe the system in this chapter can be found in Appendix A.

5 MEASUREMENTS

5.1 Analyzed parameters

When designing a fuel cell system the most important parameter is the power consumption. In order to calculate this, the voltage and current must be known. In boats, each phase of the three phase system is used for different applications which leads to that they differ a lot from each other in the current and thereby in the power. Therefore it is important to measure on all three phases at the same time. The voltages are essentially the same but all three phases are measured to get an exact value of the power.

The voltages and currents that were measured are the three phases from the generator. This was done because the energy consumed in the ship during sea travel is produced by the generator.

5.2 Measurement equipment

The measurement equipment consists of the measurement instrument Unilyzer 901, different devices for measuring currents and voltages, PC (Personal Computer) and communication cable or modem cable. In Figure 11 Unilyzer 901 is presented together with voltage and current measurement devices. The company manufacturing Unilyzer 901 and the software that belongs to it is called Unipower.

Figure 11. Measurement unit, Unilyzer 901. The small black box, seen to the left, is the coupling device for the voltage measurements and has four inputs. The orange coil, in the center, is a Rogowski coil used for AC current measurements.

5.2.1 Unilyzer 901

The instrument that was used for the measurements is the Unilyzer 901, borrowed from the Institute of Electrical Power Engineering at Chalmers University of Technology. The instrument is capable of measuring different electrical units, e.g. voltage, current, power, frequency, transients, etc. Unilyzer 901 is able to measure four currents and four voltages simultaneously. It can measure different electrical grid configurations such as 3-wire system, 4-wire system, phase-to-phase and different Y- and Δ-connections [8].

The measurement unit is based on a 32-bit DSP (Digital Signal Processor) and has eight inputs which are moist and dust proof. It can be equipped with different current probes depending on different needs. For AC current measurements Rogowski coils (0-2000 A) can be used and for DC current measurements DC current probes can be connected to the device [8].

When the instrument is switched on, it starts to measure and saving the data continuously until it is switched off. The unit has a memory of 4 Megabytes which does not appear to be much, but since the saved data files are quite small in size, it means that the memory will last a rather long time. When the memory is full it starts to write over the old measurement data [8].

Unilyzer 901 has a sampling frequency in the range of 6.4 – 12.8 kHz in a 50 Hz system. In the unit configuration the user chooses the sampling interval, i.e. how often the data is stored. Unilyzer 901 samples the data constantly at a frequency in the range and a mean value of the sampling interval is stored. With this method of collecting data, information about variations in the measured quantities can be lost but Unilyzer 901 saves the max and min values which can be shown in the plot. However the sampling interval has to be adjusted to the occasion, e.g. if the measured quantities have a lot of fast variations the interval has to be small for the curve shapes to be obtained [8].

The accuracy of the device is about ±0.2% for both voltage and current channels in the temperature area of 0 – 40°C [8].

5.2.2 Software

There are two different computer programs from Unipower that are used together with the measurement device. A short summary of their functions is given below.

5.2.2.1 PQ Online

PQ Online is a program that is mainly used for the configuration of Unilyzer 901. The configuration can be done either at the site of the measurement or by modem communication. The program can also be used to study the measurements in real time, create files from the instrument and analyze disturbances in them [8].

In the real time analysis all the measured quantities are shown. The voltages and currents are shown for each phase. Unbalance between the phases and the frequency can also be seen. The active, reactive and apparent power are shown for each phase as well as the sum of all three phases [8]. All this can be seen in Figure 12.

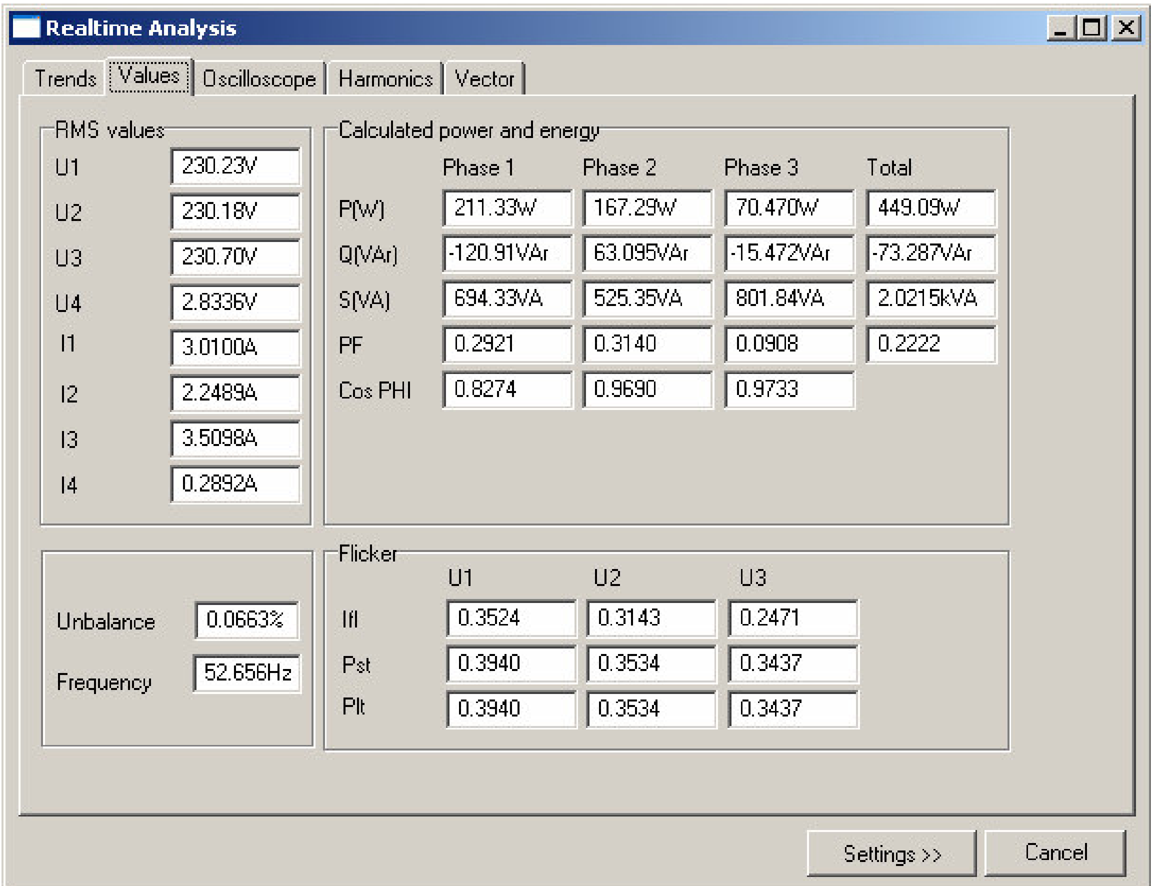


Figure 12. Real time analysis where the measurement data can be monitored live.

When starting the unit configuration, the first thing that is done is to describe how the unit is connected, i.e. if it is 4-wire-, phase-to-phase connection, etc. To make it easier for the user, all the connection schematics are shown graphically in the program. There is also a possibility to multiply data with a constant to alter the scaling in the program [8]. This can be seen in Figure 13.

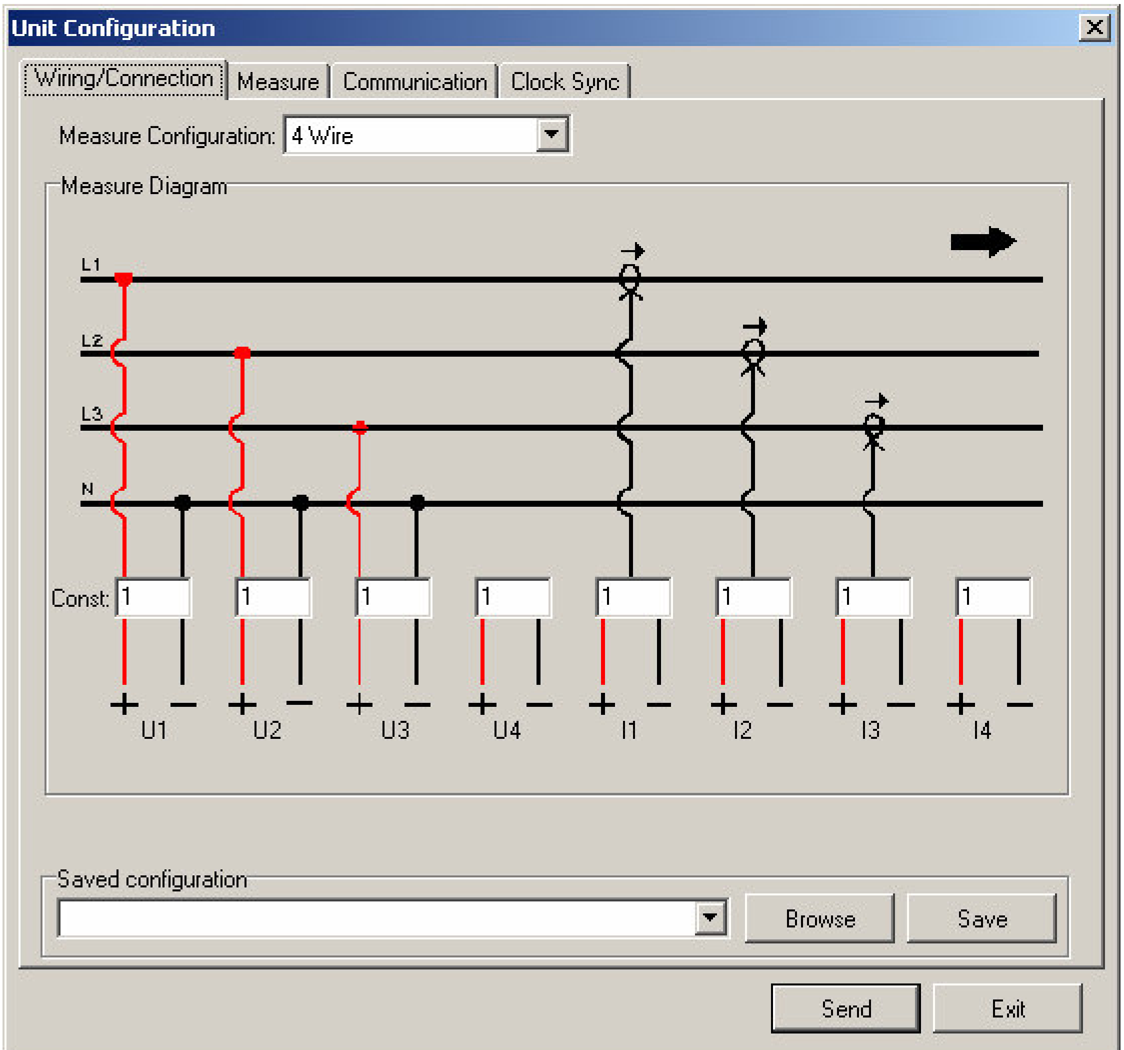


Figure 13. Unit configuration where different kind of wiring and connection settings can be made.

The second step of the configuration is to decide how the measurements should be stored. Different sample intervals can be set for each of the measured quantities. This means that shorter intervals can be chosen for the interesting quantities, which gives better accuracy, and longer for the rest [8]. Figure 14 shows how it looks in the program.

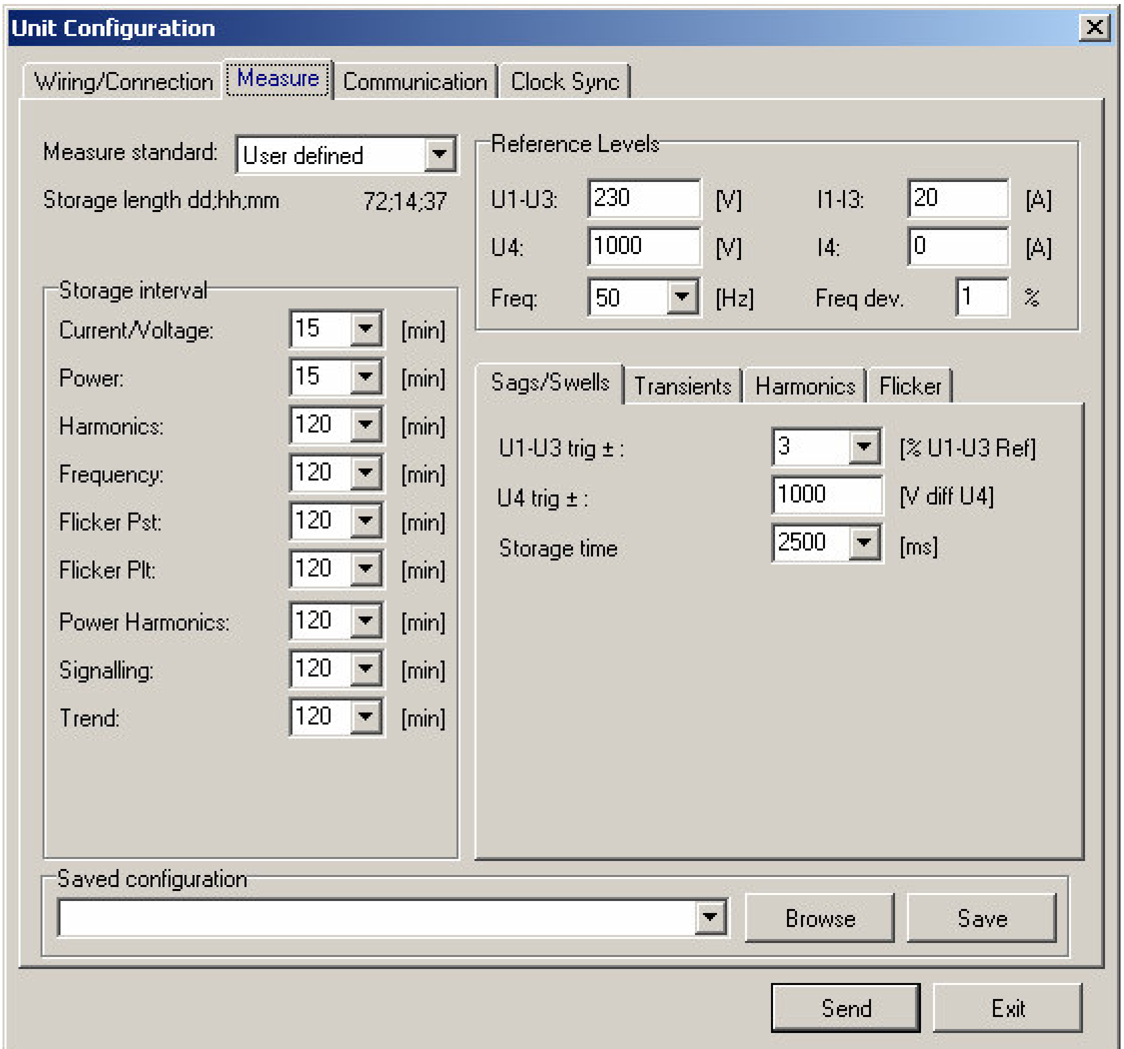


Figure 14. Unit configuration where the sample time and reference levels are set for the different measurable parameters.

PQ Online is not only used for the configuration of the instrument but also for downloading the data. When the data has been downloaded the instrument can be emptied of the information. The collected data is then analyzed using another Unipower program called PowerProfile.

5.2.2.2 PowerProfile

PowerProfile (PP) is a Windows based program that is used for evaluation of the collected data from Unilyzer 901 and similar measurement instruments from Unipower. The program shows the measurements graphically with the possibility to choose which parameters that should be plotted. Different measurements such as voltage, load analysis, voltage quality, harmonics and temperature can be evaluated with this software [9]. An example of how measurements are presented in PowerProfile can be seen in Figure 15.

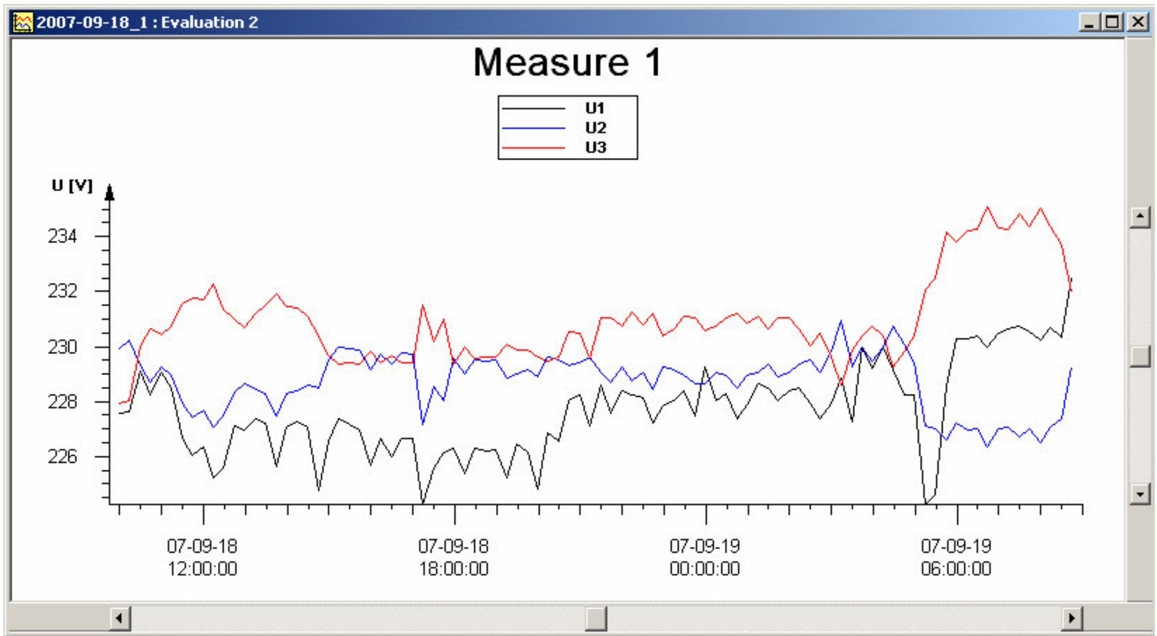


Figure 15. Example on how a measurement presentation in PowerProfile looks like. In this case the presented parameters are the phase voltages from the generator in the ship.

The diagrams that are created in PP can easily be printed, plotted or copied to other programs such as word processors and mathematical programs [9].

5.3 Installation of equipment

The plans for the ship during autumn were a one month trip from the west coast of Sweden (Hälleviksstrand) to the east coast (Stockholm) and back. This trip consisted of several shorter stages where the ship rested in harbor between each stage.

The equipment was installed at Hälleviksstrand about a week before the departure date. The measurement instrument was safely placed in a compartment under the electric central located in the wheelhouse. All cables used for the measurement including the power supply for the instrument were drawn from the underlying compartment up into the electric central. The voltage cables were directly connected to the output phases of the generator. The Rogowski coils used for the current measurement were placed around the phase cables. The power supply for the instrument and the modem were taken from one phase of the generator output.

The configuration of the unit was set for the important values to be stored at a higher rate than the less interesting ones. The voltages and currents were saved every 15 minutes and the rest of the measured quantities more seldom. The reason for this is that if the quantities are stored more frequently the memory of Unilyzer 901 will be full at a higher rate. With a less frequent storage the accuracy will be worse.

5.4 Performing the measurements

During the first stages of the trip the plan was to download the data on board via the communication cable between the PC and the instrument. This was done to be sure that the equipment functioned the way it was supposed to and to get some documentation about where the power was consumed. The dimensions of different areas in the ship were measured and photographed for the purpose of finding a place where the fuel cell system possibly could be installed.

When it was confirmed that the system worked as planned the measurement downloads were made from land via modem communication. The time for downloading the data in this way was longer than when it was done on board.

5.5 Data analysis

When the measurements were finished, the first program that was used to analyze the data was PowerProfile. This was used for studying voltages, currents, power and energy delivered from the generator. The possibilities for analysis are however limited. The measured values can be plotted and different quantities can be shown in the same graph. There is also a possibility to see minimum and maximum values for all the parameters but this is as far as the analysis goes. Another thing that has to be kept in mind is that depending on when data is downloaded a disorder in the files can emerge. This means that values from the same day can end up in different files which make the analysis harder in PP.

Since PowerProfile has limitations some other program had to be used. A mathematical program called Matlab was used at the beginning of the measurement analysis. To access the data in Matlab a conversion of the PP file must be done using PFExport which is another Unipower program. The new file is a Microsoft Excel file which is easily imported and read in Matlab. In Excel different files from PP can be linked together to overcome the problem of disorder described above. In the end it was Excel that turned out to be the most useful program in the analysis.

5.6 Results of the measurements

As mentioned before the phases in the 400/230 V systems are used to power different appliances. This can be seen in Figure 16 where the phase currents are seen to differ from each other.

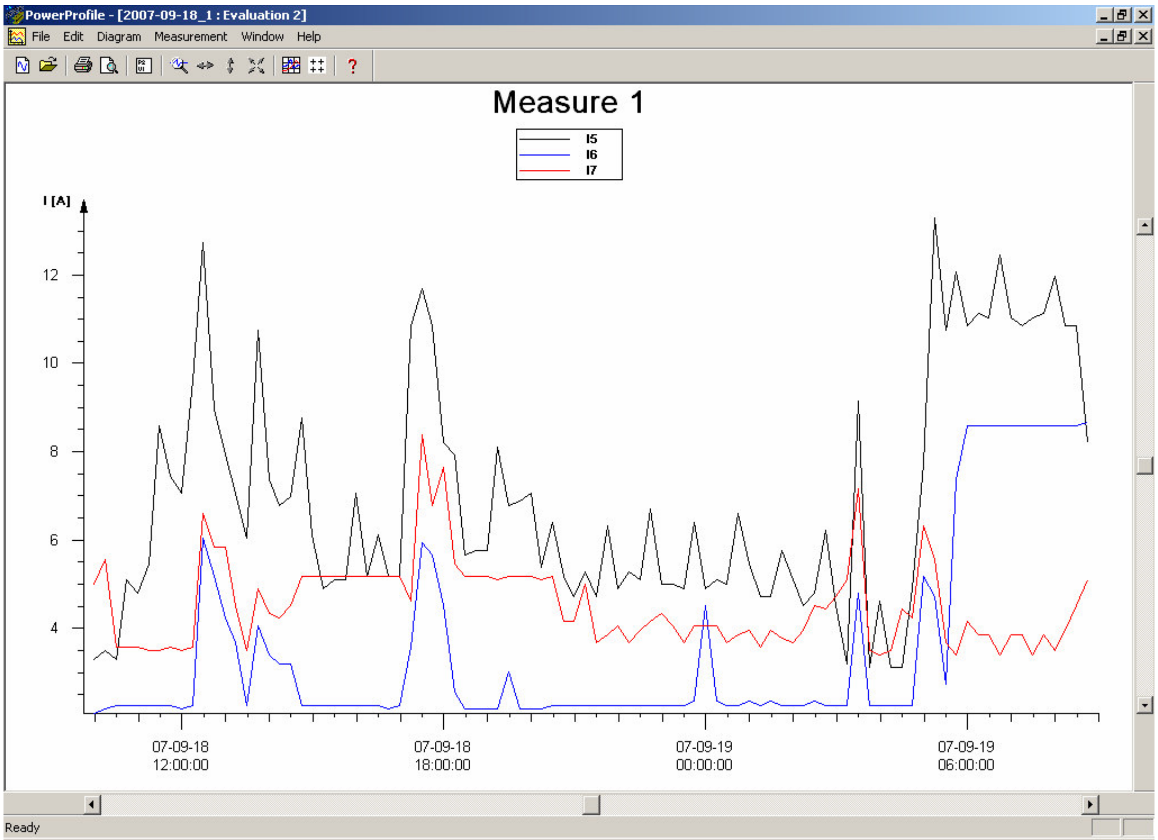


Figure 16. Data from the generator three phase current measurement.

The power outtake during 24 hours has the same shape as the current due to that the voltage is more or less constant over time. The power for the same time period as for the current above can be seen in Figure 17. From this figure one can see that the maximum power drawn is about 5.3 kW and that the peak powers appear at breakfast, lunch and dinner time. This is because of the use of the oven, fans and other kitchen appliances. The shape of the power will look essentially the same from one day to another due to that the routines on board are similar.

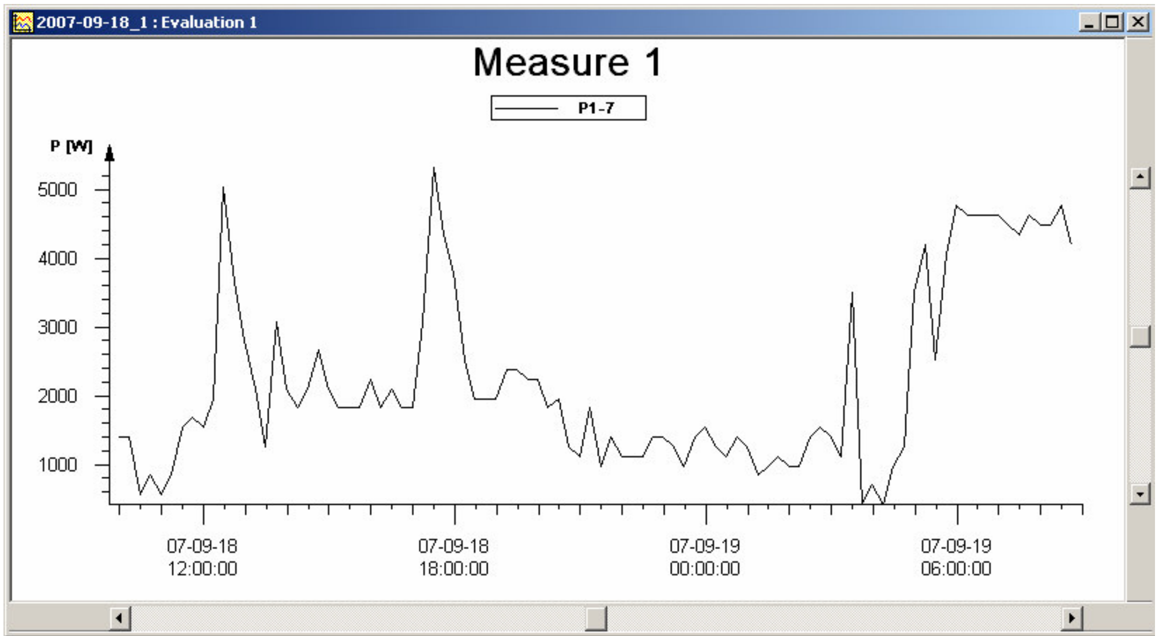


Figure 17. Power consumption for a one day and night sailing trip.

The time period for the energy, seen in Figure 18, is the same as for the power measurement. The mean value of the energy is around 550 Wh. The transformation factor between energy and power is four since the sample interval was chosen to be 15 minutes.

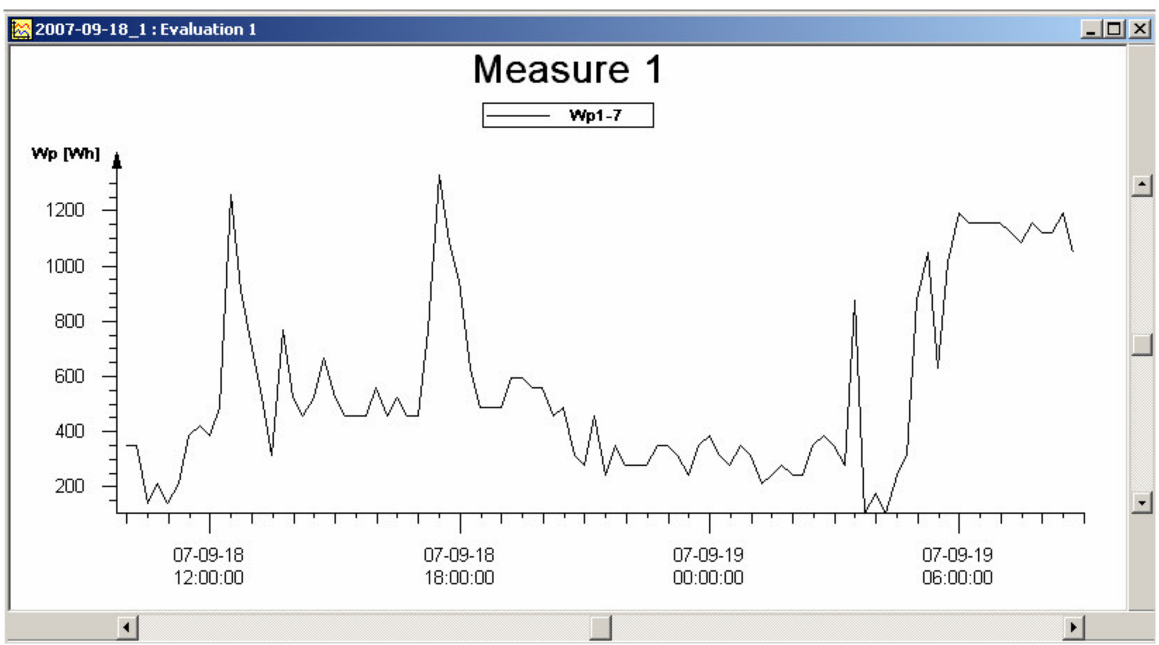


Figure 18. Energy consumption for a one day and night sailing trip.

6 DESCRIPTION OF A FUEL CELL SYSTEM

Although the design part should be taken care of by the contracted supplier, a principal description of a fuel cell system is gone through in this chapter. First an example of how to calculate the stack size is performed. In the following subchapters the different parts that may be needed in the system are presented.

6.1 Fuel cell stack

The parameter that will be crucial for the size of the stack is the maximum power that should be delivered. As an example, a maximum power level of 2.5 kW is chosen. The reason for choosing this specific value will be explained in chapter 8.

6.1.1 Size

The first step to obtain the size of the fuel cell stack is to calculate the number of cells needed to deliver a specific voltage level. The cell voltage is chosen to 0.7 V based on the voltage-current density graph seen in Figure 19. At 0.7 V the power is about its maximum value. In this example the needed voltage will be assumed to be 230 V. The number of cells will be 329 (328.57) when the fuel cells produce this voltage.

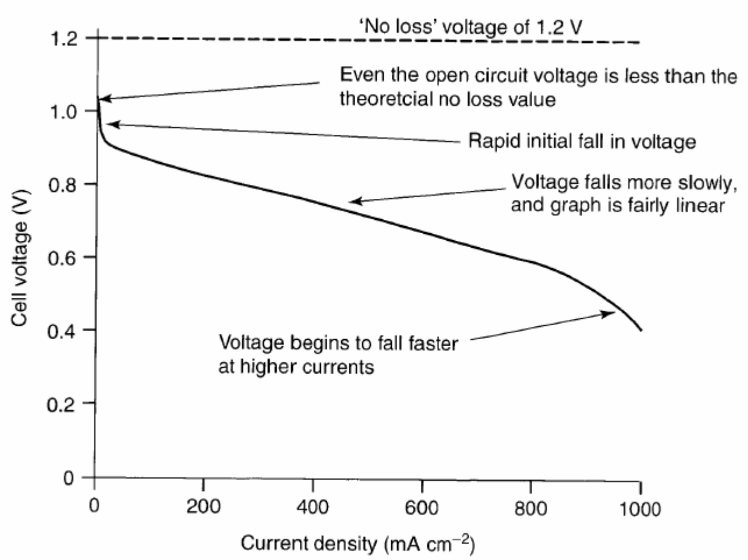


Figure 19. Voltage-current density diagram for a low temperature, air pressure fuel cell. Courtesy of John Wiley & Sons Limited [P1].

The total current from the stack when supplying the maximum power can now be calculated.

$$P = U \times I \quad \Rightarrow \quad I = \frac{P}{U} = \frac{2500}{0.7 \times 329} = 10.86\ A \qquad (6)$$

Where,

P = Power [W]
U = Voltage [V]
I = Current [A]

For a specific power rate, the current can be increased or decreased, depending on the need of the load, if the voltage is altered by changing the number of cells. If the needed voltage is different from the stack voltage, a voltage regulator could be used to achieve the right level.

From Figure 19 it can be found that the current density for 0.7 V is around 550 mA/cm^2. The area of each cell can now be calculated using the current calculated in equation (6).

$$A = \frac{I}{J} = \frac{10.86}{0.55} = 19.7\ cm^2 \qquad (7)$$

Where,

A = Fuel cell area [cm^2]
J = Current density [A/cm^2]

The total size of the stack depends on this area, the number of cells and the thickness of each cell. This thickness depends on material and design and will not be discussed further.

6.1.2 Fuel cell types

There are two main groups of cells that are available, low temperature and high temperature fuel cells. What determines which type to use is the field of application. In low temperature cells the hydrogen has to be more pure than in the other case. In the case of high temperature cells, hydrogen can be produced internally in the stack by reforming other fuels, such as Liquefied Petroleum Gas (LPG), methanol, etc [6]. For low temperature cells a reformer is used for this purpose. Another thing to keep in mind is that the exit gases and cooling fluids in high temperature cells can be used to heat buildings, processes and facilities near the fuel cell. The exit gases can also be used to drive turbines that can drive generators, producing further electrical power. This means that the high temperature cells are suitable for CHP applications [3].

A list of different commercially available fuel cells with manufacturer, application area, power output, product dimension and efficiency can be found in Appendix B.

6.2 Converters

6.2.1 DC/DC converter

In the calculations on the fuel cell stack the number of cells is chosen with respect to that the voltage over the stack should have the same voltage as the grid voltage. If for some reason the number of cells is chosen differently a DC/DC converter can be used to achieve the right output voltage level [5].

The voltage over the stack is normally not constant and when the current increases there will be a voltage drop. In fuel cells this voltage drop is greater than in normal electrical power generators. In this case there is also need for a DC/DC converter to solve this problem [5].

6.2.2 DC/AC inverter

As mentioned in the chapter on fuel cells the output from a stack is a DC current. In the ship the fuel cells will be used to deliver power to the 400/230 volts three phase system and for this purpose an inverter will be needed. When using a DC/AC inverter there is no use for a DC/DC converter because it is also capable of regulating the output voltage level [15].

6.3 Hydrogen storage

To be able to use hydrogen as a fuel the first thing to look into is how to produce and get the hydrogen to the boat. There are different ways of achieving this and the most common ways are by buying H_2 tubes, by using an electrolyzer or by using a reformer. Irrespective of which method that is utilized the hydrogen will be stored under pressure in tubes in the boat. The biggest problem is to find a good place to store the fuel on board. If it is below deck then a well ventilated and safe area is needed to prevent accidents. An interesting observation to keep in mind is that hydrogen will take a lot of room at low pressures. To illustrate how the density varies with the pressure, an example is that 1 m^3

contains 0.1 kg H_2 at a pressure of 1 bar and 15 kg H_2 at a pressure of 200 bar. Another interesting fact is that one kilogram of hydrogen has the same energy content as one gallon (about 4 liters) of gasoline [6].

6.3.1 Delivered hydrogen tubes

At the moment hydrogen fuel is far less available than diesel which will make it more difficult to acquire. However, AGA is able to deliver hydrogen gas tubes everywhere in Sweden. In these tubes the gas is compressed up to 200 bar. The tubes come in three different sizes – 10, 20 and 50 litres. An advantage of buying from AGA is that the hydrogen is produced by an electrolyzer which leads to pure hydrogen [11].

6.3.2 On board production using a Reformer

Fossil fuels such as LPG, diesel, etc, can be reformed into hydrogen by using an additional component called reformer. By using this component other fuels than hydrogen can be used for regular fuel cells. This can be an advantage since there is an already available diesel tank in T/S Prolific. By using hydrogen reformed from diesel, the pollution will be less than if the diesel is used in the generator because of the higher efficiency of the fuel cells and the fact that the generator runs idle most of the time [6].

6.3.3 On board production using an Electrolyzer

The theory of this is based on the electrolysis of water. By letting a current pass through the water, hydrogen and oxygen are separated [1]. With this method the hydrogen is produced with an electrolyzer and is stored in tubes. The idea behind this is that the fuel production will be taking place on board when the boat lies in the harbor using the shore connection. The greatest advantage of this method is that the dependency upon others is reduced and, as in the case with AGA, the produced hydrogen is very pure. The main disadvantages are the additional cost of the electrolyzer and that it takes up extra space in the boat. Considering this and the fact that AGA is able to deliver H_2 tubes to the harbor, then this idea seems to be out of the question.

6.4 Additional components

To provide cooling to the fuel cell stack, air has to be circulated in the system. Oxygen and fuel has to be supplied to the cathode and anode respectively. For these purposes compressors, fans, blowers and pumps have to be used [4].

6.4.1 Compressors

The compressors that are used in fuel cell systems are of the same type as those used in other engines. There are four main types of compressors [4]. They will just be mentioned briefly but their function will not be presented here.

The simplest is the Root compressor which is cheap to produce and it works over a wide range of flow rates. These compressors are commonly used as superchargers for petrol engines in cars [4].

Another type is the Lysholm or screw compressor which has the advantage that it can be designed to provide a wide range of compression rates up to eight times the input pressure. Unlike the Root compressor the screw compressor is quite expensive to manufacture due to that the rotors need to be produced with high precision [4].

The most common compressor is the centrifugal or radial type. It is used in the majority of engine turbocharging systems. The centrifugal compressor is cheap, well developed and available over a wide range of flow rates. A problem with this type is that the rotor must rotate at a very high speed and then the lubrication of the bearings must be done regularly [4].

The last one is the axial flow compressor which has roughly the inverse structure as the turbine used in gas and steam thermal power systems. This compressor is expensive to manufacture and it is used for systems above a few mega watts [4].

6.4.2 Fans and Blowers

Fans and blowers are used for cooling purposes and they are available in a wide range of sizes. The normal axial fan, which is used as cooling device in many types of electronic equipment, is an excellent unit for moving air but only when dealing with low pressures. At higher pressures a centrifugal fan can be used to blow the air in heating units. It functions in the way that it draws air in and throws it out sideways [4].

6.4.3 Pumps

A very simple type of pump is called Ejector which has no moving parts. It has the ability to circulate hydrogen gas if it is stored under high pressure or to recycle anode gases [4].

For some fuel cells the pressure needed to circulate the reactant gases is too high for the ejectors to work properly. For these applications a different type of pump called Diaphragm pump or Membrane pump is used [4].

7 ADDITIONAL POWER PRODUCTION

The fuel cell system is going to be designed to cover the low power consumption. What this means will be explained in the next chapter. To be able to use the fuel cell system a larger part of the time, extra systems for producing electrical power could be installed to cover a part of the power consumption in the boat. At first, different ideas were thought of but some were sorted out because they were considered to be non realistic. The three suggestions that could be used are presented here.

7.1 Energy extraction from the propeller

In the present system the propeller shaft is locked in place mechanically when traveling by sail. If the shaft is not locked when the motor is not running it will rotate due to the movement in the water. This leads to extra heat and that the bearings take harm due to that they are not lubricated when the motor is not running. An idea to eliminate this problem and at the same time extract energy from the propeller is to transfer the mechanical energy into electrical via a generator. To achieve this, the shaft has to be decoupled from the motor and the movement has to be transferred to the generator shaft by cog wheels. This is a good idea of extracting extra energy since it is already available and in the present system it is just wasted.

7.2 Photovoltaic cells

A complication with solar cells is that a large area is needed to produce relatively small amounts of power. The only possible place that Photovoltaic (PV) cells can be placed is at the roof of the wheelhouse. The disadvantage of placing them there is that the mast is located above the cabin. This results in that there will be people climbing on the roof and therefore the PV cells have to be resistant to pressure and hits. Also, the sail will cast shadow and the cells will not have the ultimate angle towards the sun due to that the roof is almost horizontal. Another disadvantage is that sea travel involves salt, water and wind which leads to a reduced performance of the cells.

7.3 Wind power

A small wind power station could be placed in the stern of the ship to produce extra power. The turbine is normally located at a height of five meters and has a diameter between 0.5 and 1 meter. The output power is very wind dependent and it increases with the cubic of the wind speed. It has also a dependency on the square of the turbine radius. Since the diameter of the turbine in boats is small in comparison with stationary wind power plants the output power is quite small, e.g. 67 W for a 1 meter turbine at a wind velocity of 7 m/s [15].

8 HYBRID FUEL CELL SYSTEM

The existing diesel generator in T/S Prolific seems to be over dimensioned when studying the power consumption of the ship. This means that the generator runs almost idle most of the time. The consumption of diesel in the generator is not proportional to the output power. In idle running, it consumes about 30 – 40% of the amount of diesel that is used to generate the maximum power [15]. For this reason, a good idea to reduce the use of the diesel generator is to have another system for the power generation that is capable of delivering the low power.

The hybrid system that was studied for T/S Prolific consists of the existing diesel generator and the new fuel cell system. The idea for the fuel cells is to deliver as much of the needed power as possible. The limits are the cost as well as the size of the new equipment. Also, there is no need to dimension the fuel cells to deliver the peak powers as they often occur for short periods and these variations results in shorter lifetime of the cells. These peaks are instead covered by the diesel generator or by the batteries via the inverter.

This chapter is dedicated to the parameters for the specification of requirements for the design of the hybrid system. The most important aspect to study is how the power consumption varies for a 24 hour time period. How this is done and the other aspects to consider before the specification of requirements is completed are presented in this chapter.

8.1 Power consumption study

To get a general view of the power consumption the idea was to divide it into different levels. The different levels correspond to a percentage of the total time.

The time frame of the studied measurement data used for the division of the power consumption was between the 13th of September and the 10th of October of 2007. During this period the number of measurable days were almost fifteen due to that the generator was not running when the ship was at harbor which resulted in no measurements. An example of how the data looks like over a random period of time is seen in Figure 20.

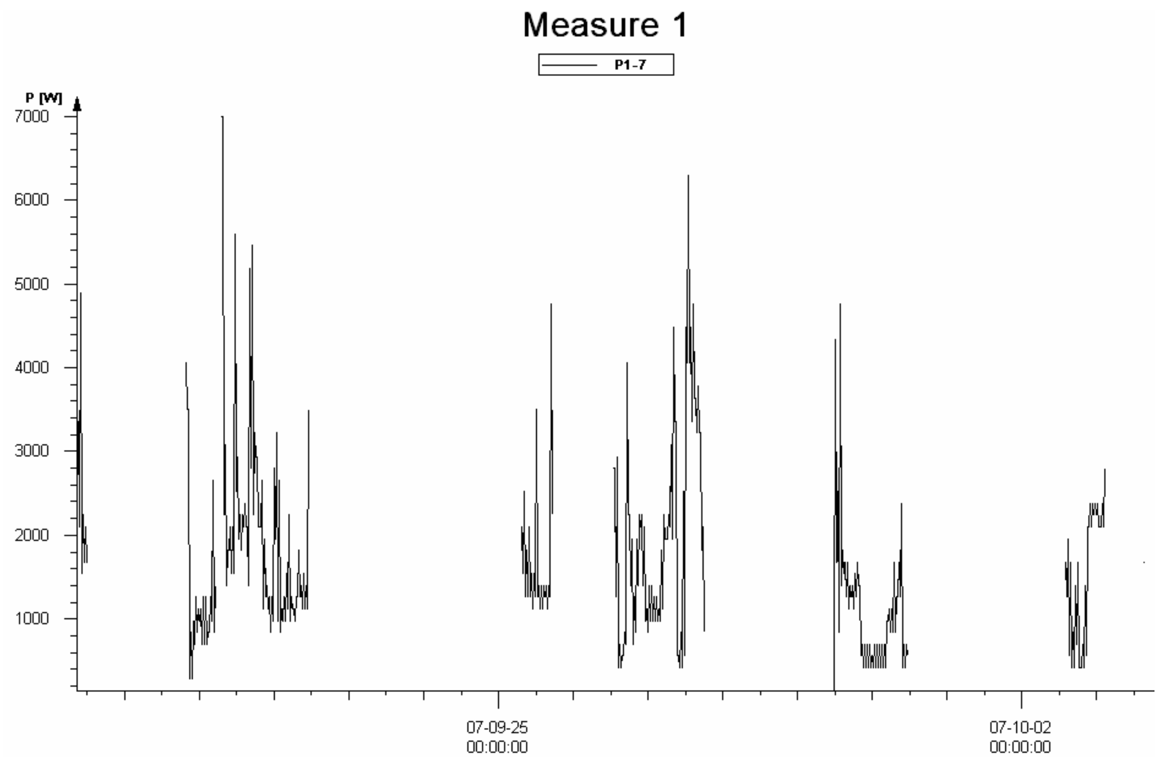


Figure 20. Power measurement during a 14 day period. The periods without measurements occurred when the ship was at harbor where the generator is not used.

To be able to identify the different levels in the power consumption, a first step was to divide it into small sections and calculate the percentage of the total time that corresponded to each section. The first division is presented in Table 1.

Power consumption [kW]	Percentage of time [%]
0-1	29.3
1-2	42.8
2-3	15.1
3-4	7.2
4-5	3.9
5-6	1.6
6-7	0.1

Table 1. Division of the power consumption into 1 kW sections.

From Table 1 it can be seen that most of the power consumption is found in the region below 3 kW. Depending on the cost and size of the fuel cell system, different scenarios for the power consumption levels are thought of. Another important issue is which time of the day the different power levels corresponds to. In order to get an idea of this the levels are compared to the measurement diagrams. The results are seen in Table 2.

Power consumption [kW]	**Percentage of time [%]**	**Time of the day**
0-1	72.1	Night and "light" day sailing
1-2		
2-3	15.1	Day sailing and night sailing combined with low use of the kitchen
3-4	11.1	Day sailing combined with full use of the kitchen
4-5		
5-6	1.7	High load
6-7		

Table 2. Division of the power consumption with respect to the time of day and the field of application.

From Table 2 it can be seen that there are three main divisions, night, day and high load. Three scenarios for the power rate of the fuel cells are constructed based on the desired capacity. The target is to design a silent system, especially for night sailing. The first scenario is therefore designed so that the fuel cells cover the power consumption during the night. The second and third scenarios are then designed to cover larger portions of the power consumption.

8.1.1 Scenario 1

The power consumption is divided into three levels, low, medium and high. The idea is that the fuel cells should deliver the low power level. As mentioned before, each level corresponds to a percentage of the time. Figure 21 shows the percentage content of each level for Scenario 1.

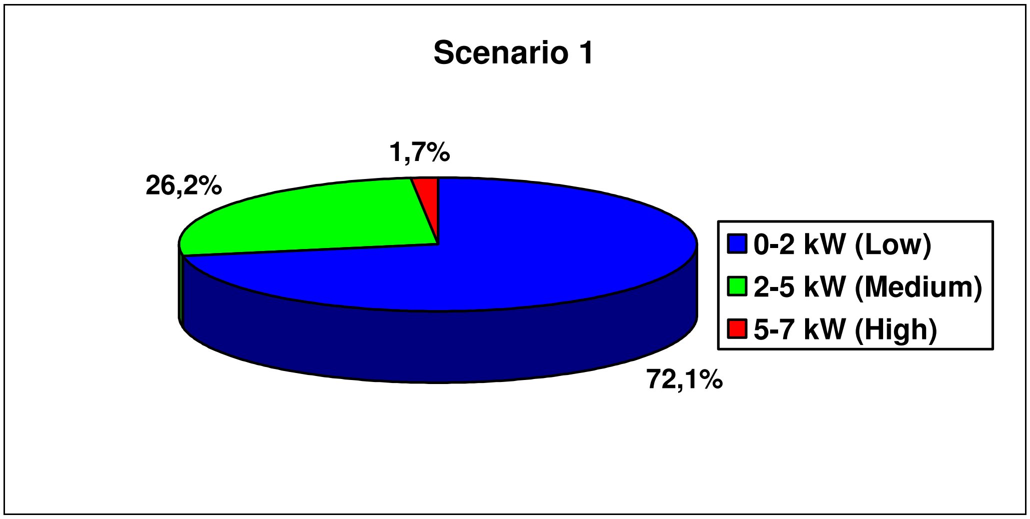


Figure 21. Scenario 1 for the power consumption levels.

As seen in Figure 21 the low power consumption section in Scenario 1 corresponds to the interval 0-2 kW. It is interesting to observe that although the fuel cells maximum output will only be a small part of the peak power, it is able to cover almost three quarters of the total time. Most of this time is during night sailing and "light" day sailing.

8.1.2 Scenario 2

Scenario 2 was based on the first one but the thought was to see what happened when the low section was increased to 2.5 kW. The result can be seen in Figure 22.

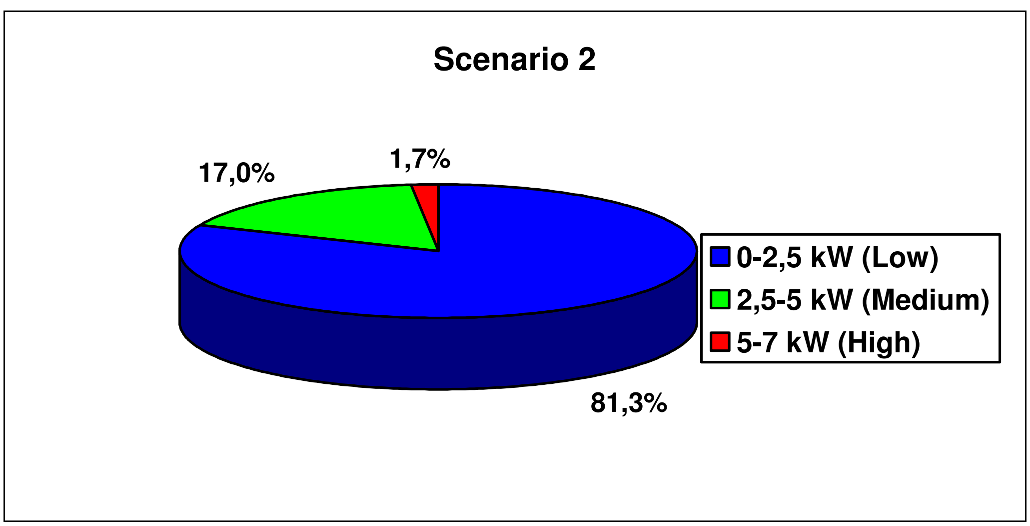


Figure 22. Scenario 2 for the power consumption levels.

The time of use for the fuel cells is increased by nine percentage units by increasing the system output with 0.5 kW compared to Scenario 1. This leads to that the fuel cells can be used for night sailing as well as for a longer time during day sailing.

8.1.3 Scenario 3

In the last scenario the low power region was increased to 3 kW. This is illustrated in Figure 23.

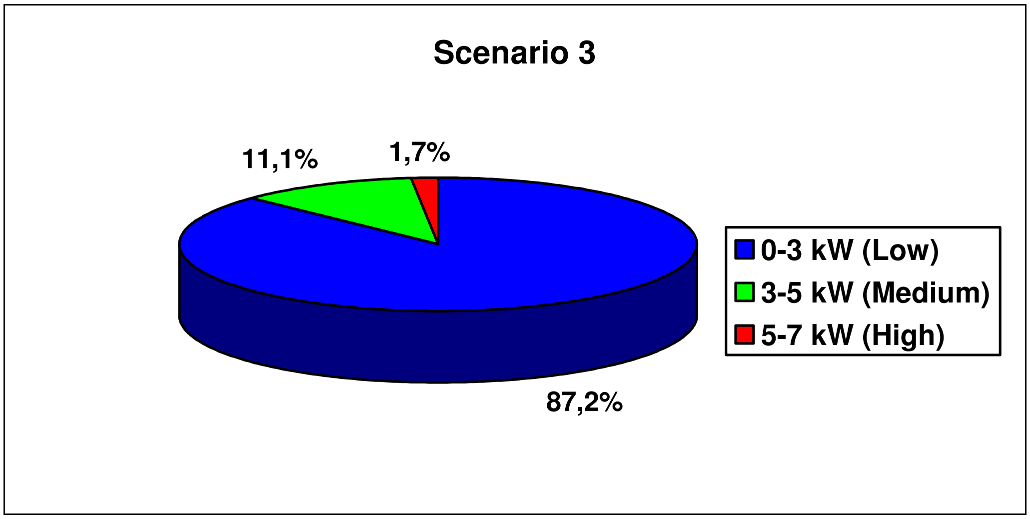


Figure 23. Scenario 3 for the power consumption levels.

In this scenario the time of use increased an additional six percentage units compared to Scenario 2. This means that the fuel cells can be used for most of the day and during low use of the kitchen.

8.1.4 Choice of Power rate

The decision for the power rate of the fuel cells was based on the time of use, as can be seen in the different scenarios above, and the behavior of the power consumption. The concept of time of use has already been explained but the second criteria need some further explanation. It means that the variations in the power consumption were studied to see if some power levels were more suitable for the fuel cells to deliver. Fast variations in the power consumption are not recommended for the lifetime of the fuel cells.

If a power rate of 2 kW were to be used, there would be some time periods with a rather constant power demand, appropriate for fuel cell use, which could not be delivered by the fuel cells because of insufficient output power. It could also be noted that most of the power in the interval between 2.5 and 3 kW were concentrated in quite fast varying peaks and would not be good for the fuel cells to deliver because the lifetime would be decreased. Therefore, after comparing the scenarios in this way, the power rate of the system was decided to be 2.5 kW. A system with this output power would cover a large portion of the total time and almost all of the slow varying power consumption.

8.2 Fuel cell system dimensions

When the desired power rate is chosen an interesting parameter for future decisions is the dimensions of the fuel cell system. It is difficult to estimate these dimensions without actually designing the system. To get a rough estimation of the size an idea is to study already commercially available systems. An example is the Swedish fuel cell company Cellkraft which offers a 2 kW system with the following specifications, Table 3.

Model	Power [kW]	Current [A]	Voltage [V]	Dim. W×H×D [mm]	Weight [kg]
S-1000	1	0 – 50	24 – 36	471×281×513	27.8
S-2000	2	0 – 50	48 – 72	471×281×513	30.2

Table 3. Specifications for a 1 and a 2 kW fuel cell system from Cellkraft.

From the table it can be seen that the size of the system is not especially large both concerning the dimensions and the weight. It is also interesting to note that there is almost no difference in size between a 1 and a 2 kW system. The fuel cell systems from Cellkraft contain all components except fuel storage and inverter. In this project a 2.5 kW system was decided to be used which can be assumed to have more or less the same dimensions as a 2 kW system. Based on observations and measurements made on board T/S Prolific, a system of this size could be placed in an over deck compartment by the stern, Figure 24.

Figure 24. Over deck compartment for the possible placement of the fuel cell system.

8.3 Choice of fuel

There are some types of fuel cells that use other fuels than hydrogen, e.g. Direct Methanol Fuel Cell (DMFC). It is called "Direct" because it uses methanol in liquid form directly as a fuel. However it is most suitable for low power portable electronics and is not designed to deliver powers of the magnitude needed for the system in this project [1]. To illustrate this, examples of power rates for DMFC can be found in Appendix B.

There is another way of using other types of fuels but in an indirect method. Fossil fuels can be reformed into hydrogen before being used in the fuel cells. One thing to mention is that an extra component, a reformer, has to be added to the system for the indirect use of fossil fuels.

Considering the drawbacks with the methods mentioned above and that AGA can deliver very pure hydrogen to the ship, the best solution for the problem of choosing fuel is the direct use of hydrogen.

8.4 Energy and fuel estimation

The objective of this chapter is to calculate the quantity of fuel needed for the fuel cells to deliver power during an estimated time. The first step is to find out the energy consumed for the level below 2.5 kW, i.e. the power which the fuel cells will provide. The energy was calculated from the measurement data to be about 25.3 kWh/day (24 hours).

The energy content LHV (Low Heating Value) in one kilogram of hydrogen at room temperature and at atmospheric pressure is around 120 MJ which equals 33.3 kWh (E_{H_2}). To be able to know the quantity of hydrogen that is going to be stored on board, the number of days that will be spent at sea without any possibilities to refuel must be known. In order to calculate a reasonable value of the storage area for the fuel, different scenarios are taken into consideration.

8.4.1 Scenario 1

The first scenario is based on the boat trip that was used for the measurements. During this voyage the different stages at sea were not longer than 2 days. For this reason the first calculation is done with 48 hours as the time frame.

$$E_{2days} = 25.3 \times 2 = 50.6\ kWh \tag{8}$$

$$m = \frac{E_{2days}}{E_{H_2}} = \frac{50.6}{33.3} = 1.52\ kg \tag{9}$$

Where,

E_{2days} = Energy during two days delivered by the fuel cell system [kWh]
E_{H_2} = Energy content of one kg of H_2 [kWh]
m = Mass of the hydrogen [kg]

As said in chapter 6.3 AGA delivers hydrogen gas tubes at a pressure of 200 bar. At this pressure the volume needed for 15 kg of H_2 is 1 m^3. It is easy to see that the mass needed for two days has a volume of one tenth of a cubic meter (100 dm^3) with this pressure. This volume can be decreased if a higher pressure is used.

8.4.2 Scenario 2

This scenario is made up to see the difference in mass if the trip at see is chosen to be longer. The number of days will now be five. Using formula (8) and (9) the mass of the hydrogen gas is calculated to 3.80 kg. In this case the volume will be one fourth of a cubic meter (250 dm^3) with the same pressure as in scenario 1.

With formulas (8) and (9) different scenarios can be constructed with the desired number of days.

8.5 Control of the hybrid system

In most modern systems some type of control is used for the purpose of reliability, durability and safety. The system also becomes more user-friendly and easy to operate. This control system will be based on power electronics which can be found in many different applications. In the following subchapters the different possibilities for controlling the hybrid system are mentioned.

8.5.1 Switching between generator and fuel cells

The fuel cell system is able to deliver a certain maximum power to the loads. When this limit is exceeded the generator should be switched on and the fuel cells should be switched off. When the power consumption goes under the limit the opposite takes place. This switching would not work if done manually due to that it would be almost impossible to do this every time it should be necessary. The solution to this problem would be the use of a control system for switching when the limit is passed either way. The use of such a control system allows the fuel cells to be used for the estimated time.

The switching between the diesel generator and fuel cells could lead to reduced lifetime for the fuel cells as well as for the generator. To reduce the number of switch-overs batteries could be used to cover the excess energy for a short period of time.

8.5.2 Load control

Another way of controlling the hybrid system is to control the power consumption itself. This is done by switching off certain loads that are not important at times when the consumption rises above the fuel cell limit. To achieve this, the loads have to be ranked on a scale from the least to the most important. The advantage of this method is that the switching between the generator and fuel cells becomes less frequent leading to less strain on the whole system.

8.6 Block diagram

The hybrid system with fuel cells and generator can be seen in Figure 25. As explained in chapter 3 the output voltage from the fuel cells is DC and therefore an inverter is needed which is located after the fuel cells in the block diagram. The Control box has the function of controlling the turn on and turn off of the generator and fuel cells when switching between them. The box named "LC" is the load control and is used to switch off certain loads if necessary.

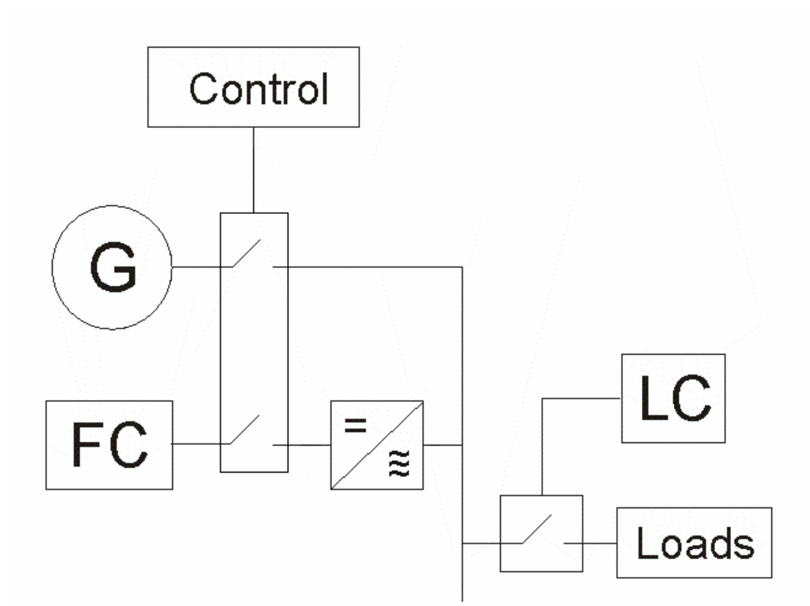


Figure 25. Block diagram of the fuel cell and generator hybrid system, where FC are the Fuel cells, G is the generator and LC is the load control. This is a simplified schematic of the three phase part of the system.

9 ALTERNATIVE HYBRID SYSTEMS

As an alternative for the hybrid fuel cell system explained in chapter 8 there are other possibilities and two of them are described briefly in this section. The first possibility is to use batteries instead of fuel cells together with the generator; a block diagram of this can be seen in Figure 26. The second is to replace the generator with batteries and use them together with fuel cells; a block diagram of this can be seen in Figure 27.

9.1 Batteries and Generator

Batteries could be used for the hybrid system instead of fuel cells. For this hybrid system new batteries have to be added and they are supposed to be charged from land with shore connection. The batteries have to deliver the same power for the same amount of time as the fuel cells leading to an energy output of 25.3 kWh/day. With a battery voltage of 24 V, their capacity has to be 1050 Ah/day. As for the fuel cell system the batteries have to be able to deliver energy for two days sailing which corresponds to 2100 Ah. This new battery system is very large and can be compared with the existing consumer batteries (650 Ah) for the low voltage applications. The capacity of the batteries can be reduced if they are charged from the generator when the generator is running.

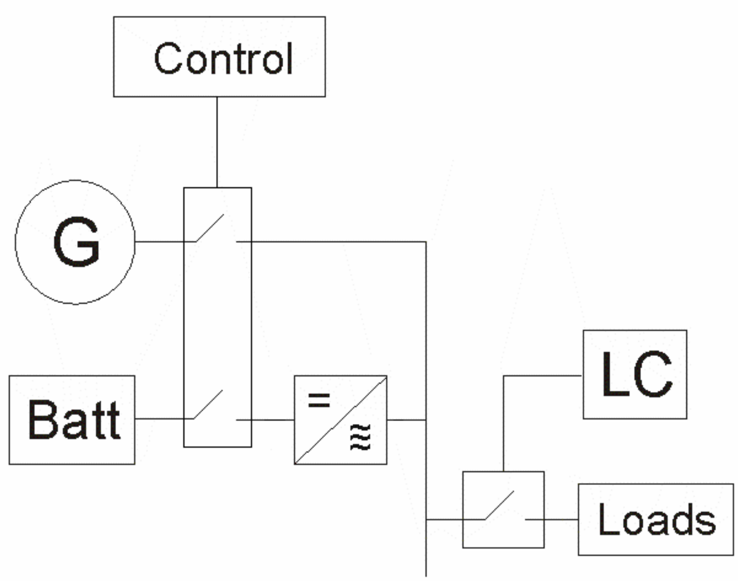


Figure 26. Block diagram of the battery and generator hybrid system, where G is the generator, Batt are the batteries and LC is the load control. This is a simplified schematic of the three phase part of the system.

9.2 Fuel cells and Batteries

The fuel cells are intended to have the same function as in chapter 8 which means that the fuel cells will have a power rate of 2.5 kW. The batteries will replace the diesel generator and are meant to deliver the peak powers. The difference for the fuel cells in this system is that they will be running constantly whatever the power consumption is. If the needed power for the ship is below 2.5 kW the fuel cells delivers this power and at the same time charges the batteries. When the needed power is above 2.5 kW the batteries delivers the surplus. Since the fuel cells will be running all the time the needed amount of fuel will increase compared to the calculations in chapter 8.

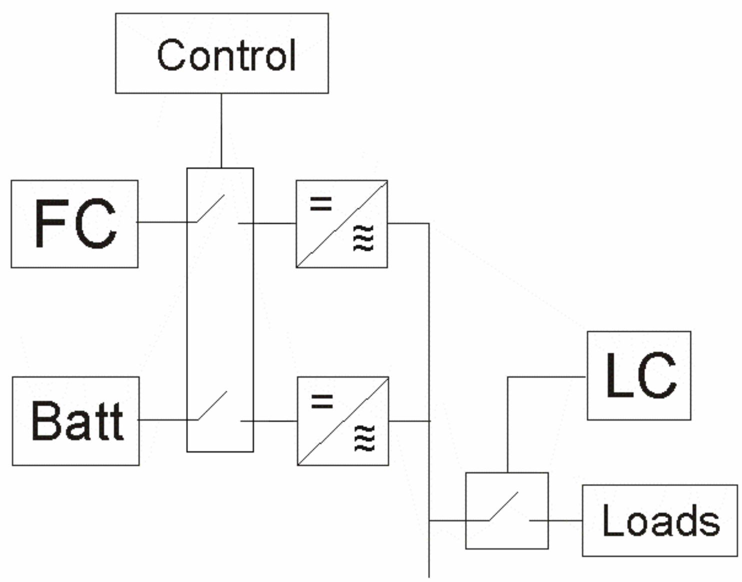


Figure 27. Block diagram of the fuel cell and battery hybrid system, where FC are the Fuel cells, Batt are the batteries and LC is the load control. This is a simplified schematic of the three phase part of the system.

10 SPECIFICATION OF REQUIREMENTS

In this part, the parameters calculated for the fuel cell system in chapter 8 are presented in an organized way. The decision-makers and the suppliers will then get a better understanding of the system requirements. The complete list of requirements is seen in Table 4. This is the most important part of the thesis because the decisions will be made based on these specifications and the system will be designed from the values presented here.

Description	Specification
Power rating	2.5 kW
Output voltage	400/230 V
Fuel	H_2
Fuel storage	100 dm^3 at 200 bar
Control system	Power electronics

Table 4. Specification of requirements for the design of a fuel cell system for T/S Prolific.

11 DISCUSSION

One of the most important aspects during the thesis was the study of the power consumption in T/S Prolific. Different scenarios for the power rate of the fuel cell system were presented in chapter 8 to show how that affected the usage time of the fuel cells. A larger power rate allows a longer time of use which implies that a larger volume of hydrogen is needed. Another factor that influences the volume of hydrogen is the number of days at sea. The fuel cells are preferably used during night time instead of the generator for noise reasons. If a longer trip without the possibility to fuel is made, a choice of only using the fuel cells at night could be done. This maximizes the number of hours that the fuel cells could be used at night.

The different scenarios for the power rate were all chosen to be below 3 kW. The reasons for not considering a scenario with higher values were that the gain in time of use was not justified and that the power consumption above 3 kW was not even, with fluctuations and more often switching that affects the lifetime of the fuel cells in a negative way. When studying the power rate of the system in this thesis, the important factor was the technical aspects but the cost and the size of the fuel cell system were kept in mind.

As mentioned above, the power delivered by the fuel cells is preferred to be even and there are several ways of reducing the fluctuations and the total amount of power. From the analyzed measurement data it can be seen that the peak powers occurred during meal times. The electric oven is normally used and since it consumes 3.5 kW it could be replaced with a gas oven. The hotplates are already gas fired so it will not be such a big transition to install a gas oven. Another way of reducing the power consumption is to use load control where loads can be disconnected for a period of time. The peak powers could also be delivered by batteries leading to that the fuel cells can be used for a longer time period. The amount of fuel needed will then be greater than what has been calculated for.

The fuel cell system that have been studied, is for testing purposes to see the possibilities of using fuel cells in ships and to attract attention to the use of fuel cells in maritime applications. A reason for not installing a too large system is that it may not work out as planned as it is only a test. If a system capable of delivering the total amount of needed power to T/S Prolific was installed, the generator would, in all likelihood, have to be removed. The drawback with this is that the power supply would rely solely on the fuel cells. When testing a new system there is a need for having a backup system if something would go wrong.

One important aspect to keep in mind is the placement of the entire fuel cell system. A well ventilated compartment is necessary to ensure the safety on board due to the risk of explosions. If possible, the best placement is above deck where the concentration of hydrogen in the air, if a leakage happens, is not able to reach the critical level.

When people hear the word fuel cell most associate it with environmental advantages. Hydrogen as a fuel is carbon dioxide free and is not contributing to global warming. Hydrogen gas is not naturally available and has to be produced. The most common ways of producing hydrogen are by reforming fossil fuels or by electrolysis of water. The first way will lead to emissions of green house gases and the second way will be more or less free of emissions depending on how the electricity used for the electrolysis is produced. In this project the fuel is meant to be delivered by AGA where the hydrogen is produced using an electrolyzer. The delivery itself, from AGA's facilities to the ship, will contribute to emissions. AGA has distribution centers in many places in Sweden which will make these transports relatively short. However the amounts of gas delivered each time are relatively small which will lead to more frequent trips. Under normal circumstances this would not be desired but the fact that this is an experimental attempt has to be taken into consideration. If the use of fuel cells in ships should work on a larger scale, a better infrastructure for the fuel has to be achieved. This would involve fueling stations in harbors leading to fewer transports.

An alternative to using hydrogen as fuel is to reform e.g. diesel into hydrogen. Diesel is available in every harbor and there is already a diesel tank in the ship which means that no extra fuel storage needs to be added. The trips to deliver hydrogen tubes will also be eliminated and will result in a more independent support. According to Magnus Karlström the efficiency in a reformer and fuel cells is high compared to a diesel generator when it runs idle which will lead to that less diesel is used to produce the same amount of energy and then the pollution will decrease.

In the harbor the ship normally uses the shore connection for the power consumption. Sometimes there is no possibility of using the shore connection and then the diesel generator has to be used. In certain harbors there are policies against noise and exhaust and therefore the use of fuel cells could be a good solution.

As an alternative to fuel cells a hybrid system with batteries and the existing diesel generator could be used. Since the amount of energy delivered by the batteries for a two day trip is the same as for the fuel cells, then new batteries have to be installed. Also, a new inverter has to be bought because of the high power.

Another alternative hybrid system is the use of fuel cells together with batteries. For T/S Prolific it is not justified to replace the generator but for shipping companies it could be an idea when building new ships. It is more environmentally benign to use this hybrid system in comparison with the one with generator and fuel cells.

There are other ways of making sea travel more environmentally benign besides new techniques such as fuel cells. In the case of T/S Prolific the main engine propeller is braked during sailing instead of converting the mechanical energy into electric power. There are also other ways of extracting more energy to contribute to the power generation in boats. This could be an advantage when using fuel cells because less hydrogen has to be used for the power production and therefore the fuel cells could be used for a longer time period with the same amount of fuel.

If the system described in this thesis would be installed in T/S Prolific it would attract attention to the use of fuel cells in the boat industry. It could be a first step towards a more widespread commercial market which would lead to a development of less polluting power generation in boats.

12 CONCLUSIONS

The fuel cell system that is planned to be installed in T/S Prolific is intended to be silent rather than environmentally benign. This system should be capable of delivering the needed energy during night sailing and for some periods during the day. With respect to this the power rate was chosen to be 2.5 kW.

The cells used in this project will use hydrogen as fuel. The storage was designed to hold enough hydrogen for two days at sea. This amount was calculated to be 1.52 kg which is equivalent to a volume of 100 dm^3 at a pressure of 200 bar.

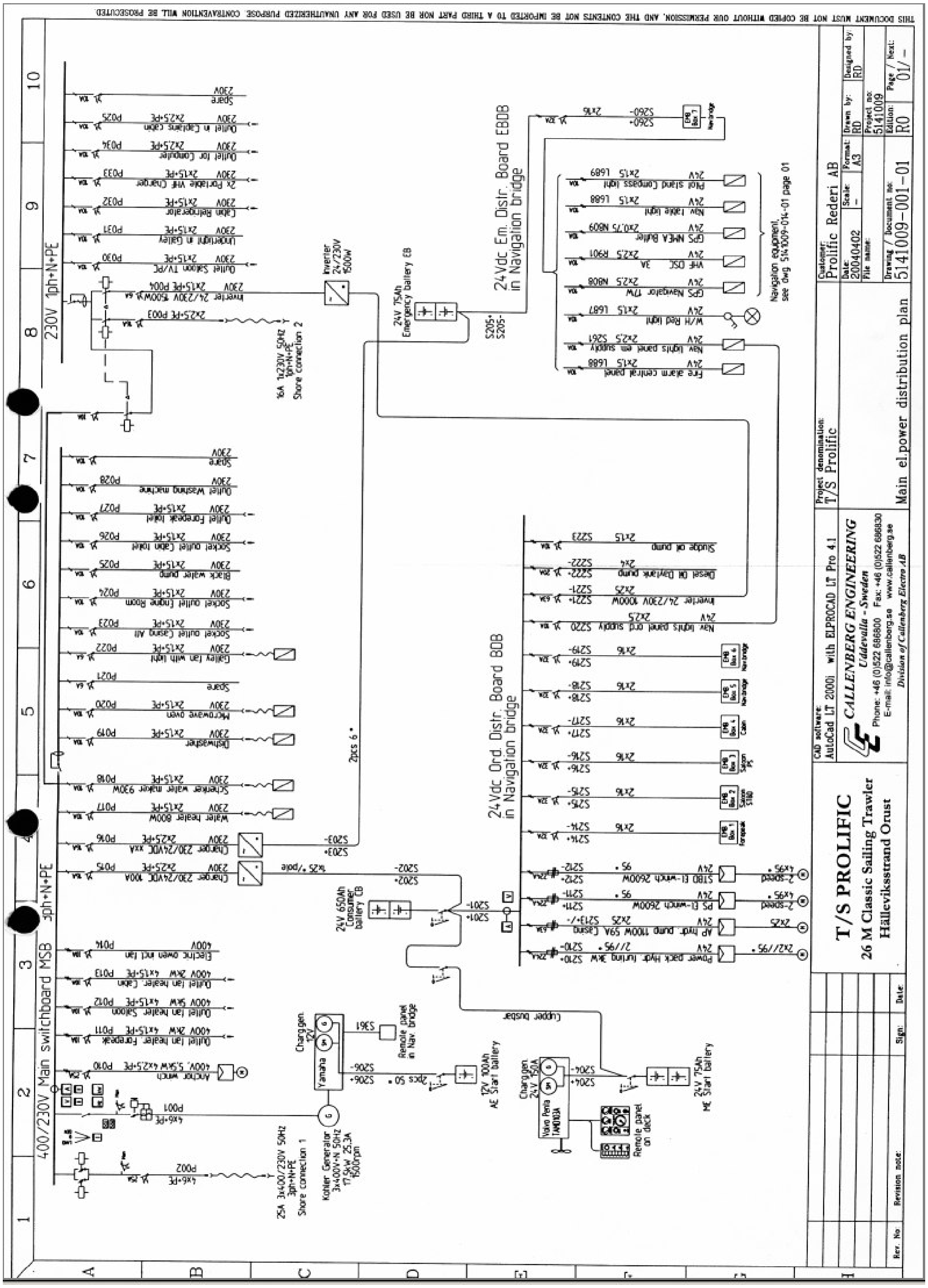
The placement of the entire fuel cell system is intended to be above deck to minimize the risk of accidents. The dimensions for a 2.5 kW fuel cell system, which does not differ a lot from that of a 2 kW system, is of reasonable size. This is a positive aspect since the compartments in sailing ships are normally limited.

This thesis is intended to be a foundation for the design and installation of a fuel cell system in T/S Prolific. As the thesis is finished it is the task of Hydrogen Sweden to carry on with the project. The owner of T/S Prolific and Hydrogen Sweden have to come to an agreement before a supplier of fuel cell systems is contacted. When this is done the specification of requirements will be sent to a supplier who will design and budget the entire system. If everything goes according to plan the system will be installed in the ship.

13 APPENDIX

13.1 Appendix A

Schematic of the electric system in T/S Prolific:


400/230V Main switchboard MSB
230V 1ph+N+PE
24Vdc Em. Distr. Board EBDB in Navigation bridge
24Vdc Ord. Distr. Board BDB in Navigation bridge
Prolific Rederi AB
CALLENBERG ENGINEERING
Uddevalla - Sweden
T/S PROLIFIC
26 M Classic Sailing Trawler
Hälleviksstrand Orust
Main el.power distribution plan
5141009-001-01

13.2 Appendix B

Different commercially available fuel cells can be seen in the following document from US Fuel Cell Council:

Page 1

US Fuel Cell Council

Commercially Available Fuel Cell and Fuel Cell-Related Product List

Manufacturer	Product Name	Application 1	Output	Fuel Cell Configuration 2	Product Dimension	Product Description and System Availability	Electrical Efficiency	Efficiency	Warranty	Product Available Today?
Ballard	Mark902	Transportation	85 kw	PEM	10"H x 32"W x 15"D	Designed to produce 85kW, 300A@284VDC using commercial grade hydrogen. Stack operated at 80C and low pressure 1-2 barg.	N/A	NA	Yes	Yes
Ballard	Mark 9 SSL	Materials Handling / Light Mobility	4.4 - 19.3 kw	PEM	2.4" x 30"W x 4.2"D (4.4kW) 2.4"H x 30"W x 6.8"D (8.8kW) 2.4"H x 30"W x 9.2"D (14.4kW) 2.4"H x 30"W x 12.8"D (19.3kW)	The Mark9SSL is scalable and available from 4.4 to 19.3kW. Multiple stacks can be used in parallel for even greater power. The Mark9SSL features fast dynamic response, robust and reliable operation in a durable package	NA	NA	Yes	Yes
Ballard	Mark 1030	Cogeneration	1.3kW	PEM	9.1"H x 17" D x 6.7" W	Reformate based, long-life and high efficiency stack. Liquid cooled stack with built in cell voltage monitoring hardware.	NA	NA	Yes	Yes
Ballard	Mark 1020 ACS	Back-up power / Light Mobility	300W - 5000W	PEM	4.4"L x 16"W x 11"D (42-Cell, 1.3kW)	The Mark1020ACS has been engineered to incorporate advanced open cathode technology and state of the art self-humidifying membranes. These features completely eliminate the need for external humidification systems and greatly simplifies system integration	NA	NA	Yes	Yes
Ballard	HD6	Transportation / Bus	65 or 130kW net	PEM	49"W x 34"W x 17"H (1x65kW module)	Ballard's next generation heavy duty PEM fuel cell power module is ideal for integration into bus applications. This module established a new standard by optimizing cost, design for volume-manufacturing, reliability, power density and compatibility with customer system requirements	NA	NA	Yes	Pre-production modules available late 2007. Production module available mid-2008
FuelCell Energy	DFC 300MA	Stationary	300 kW	MCFC	~ 30 x 30	Natural Gas or Biogas Fueled Commercial Product	47%	Up to 75%	Yes	Yes
FuelCell Energy	DFC 1500MA	Stationary	1200 kW	MCFC	~ 50 x 70	Natural Gas or Biogas Fueled Commercial Product	47%	Up to 75%	Yes	Yes
FuelCell Energy	DFC 3000	Stationary	2400 kW	MCFC	~ 60 x 55	Natural Gas or Biogas Fueled Commercial Product	47%	Up to 75%	Yes	Yes
General Hydrogen	Hydricity® Packs	Battery replacements for industrial vehicles	Hybrids with 3 to 14 kW average can exceed up to 45 kW in 5 to 30 second bursts 24V, 36V, 48V, 72V, 80V	PEM	Drop-in replacement packs including correct weight and correct Center of Gravity	Complete Pack includes hybrid fuel cell system and high pressure fuel storage for up to 24 hour run on single fill Operating temp range -20 to +40 deg C SAE J2600/1 fueling/communication	NA	NA	Standard product 2 yrs / 5000 hours	Call for delivery. Inventory changes often. 30 to 90 days for std; 4 mo ARO for specials

Page 2

General Hydrogen	F1-3000 series	Small Class 1 lift trucks		PEM	industry std, call for tray #		NA	NA	Standard product 2 yrs / 5000 hours	Call for delivery. Inventory changes often. 30 to 90 days for std; 4 mo ARO for specials
General Hydrogen	F1-5000 series	Medium Class 1 lift trucks		PEM	industry std, call for tray #		NA	NA	Standard product 2 yrs / 5000 hours	Call for delivery. Inventory changes often. 30 to 90 days for std; 4 mo ARO for specials
General Hydrogen	F1-8000 series	Large Class 1 lift trucks		PEM	industry std, call for tray #		NA	NA	Standard product 2 yrs / 5000 hours	Call for delivery. Inventory changes often. 30 to 90 days for std; 4 mo ARO for specials
General Hydrogen	F2- series	Class 2 narrow aisle trucks		PEM	industry std, call for tray #		NA	NA	Standard product 2 yrs / 5000 hours	Call for delivery. Inventory changes often. 30 to 90 days for std; 4 mo ARO for specials
General Hydrogen	F3- series	Class 3 pallet trucks		PEM	industry std, call for tray #		NA	NA	Standard product 2 yrs / 5000 hours	Call for delivery. Inventory changes often. 30 to 90 days for std; 4 mo ARO for specials
General Hydrogen	F6 series	Class 6 tow tractors		PEM	industry std, call for tray #		NA	NA	Standard product 2 yrs / 5000 hours	Call for delivery. Inventory changes often. 30 to 90 days for std; 4 mo ARO for specials
General Hydrogen	AGV serries	Automated Guided Vehicles		PEM	semi custom		NA	NA	Standard product 2 yrs / 5000 hours	Call for delivery. Inventory changes often. 30 to 90 days for std; 4 mo ARO for specials
General Hydrogen	SP series	Special Products		PEM	custom		NA	NA	Standard product 2 yrs / 5000 hours	Call for delivery. Inventory changes often. 30 to 90 days for std; 4 mo ARO for specials
Hydrogenics	HyPM XR (DC) Backup Power	Stationary	8-16 kW	PEM	75"Hx 44"W x 42"D	DC backup power system for outdoor environments (e.g. telecom installations)	55	55	Yes	Yes
Hydrogenics	HyPM XR Power Modules	Stationary	4-12 kW	PEM	38"L x 20"W x 12"H	Rack-mountable, UPS (AC) power for extended run applications (e.g. data centers)	55	55	Yes	Yes
Hydrogenics	HyPM HD Power Modules	Mobility	4-65 kW	PEM	38"L x 20"W x 14"H	Compact, high durability power module for mobility applications	50-55	50-55	Yes	Yes
Hydrogenics	HyPM Power Packs	Mobility	12 kW continuous	PEM/hybrid	38.25"L x 32.75"W x 22.75"H	HyPM power module integrated with ultracaps, hydrogen storage and thermal management, particularly suited as lead acid battery replacement for forklift vehicles	55	55	yes	Yes
Hydrogenics	HySTAT Hydrogen Station	Hydrogen Refueling	4-60 Nm3/hr	alkaline eleetrolysis	variable	Turnkey hydrogen stations with optional hydrogen storage, dispensing		~75%	yes	Yes

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IdaTech	ElectraGen™ 5	Backup	5 kW	PEM	26" x 40 x 53 (h)	Seamless Backup. Commercial	~50%	~50%	2 year	Yes
IdaTech	ElectraGen™ 3	Backup	3 kW	PEM	26" x 40 x 53 (h)	Seamless Backup. Commercial	~50%	~50%	2 year	Yes
IdaTech	ElectraGen XTR	Backup	hydrogen	PEM	28" x 28 x 53 (h)	Hydrogen generator for ElectraGen 3 & 5 using an on-board advanced fuel reforming	N/A	~80% MeOH to H2	2 year	Yes
IdaTech	iGen™	Portable	250 watts	PEM	14" x 20 x 6.5 (h)	Prime power for battery charging or portable power generation			None at present	Available on precommercial basis to qualified customer
Jadoo Power	N-Gen	Portable	100 Watt 12VDC	PEM	4.3"Lx4.3"Wx7.5"H	Fuel Cell Power Unit (includes PowerBase)	100%		2 years + optional 3rd year	Click and Buy www.jadoopower.com
Jadoo Power	XRT	Portable	100 Watt 12VDC with over 2,200 Watt-hours of run time	PEM	17.5"Lx7.2"Wx13.5"H	Extended Runtime System	100%		2 years + optional 3rd year	Click and Buy www.jadoopower.com
Jadoo Power	FillPoint	Portable	Support Equipment		14.8"Lx9.5"Wx14"H	4-Port Refill Station	N/A		2 years + optional 3rd year	Click and Buy www.jadoopower.com
Jadoo Power	FillOne	Portable	Support Equipment		8.5"Lx4.3"Wx7.5"H	1-Port Refill Station	N/A		2 years + optional 3rd year	Click and Buy www.jadoopower.com
Jadoo Power	N-Stor130	Portable	Fuel Storage Systm		2.5" dia x 4.5"H	Fuel Canister -	N/A		2 years + optional 3rd year	Click and Buy www.jadoopower.com
Jadoo Power	N-Stor360	Portable	Fuel Storage Systm		2.5" dia x 10.5"H	Fuel Canister -	N/A		2 years + optional 3rd year	Click and Buy www.jadoopower.com
Medis Technologies	Medis Power Pack	Portable	1W	Direct Borohydride	67mm x95 mm x 37 mm	Single use / disposable fuel cell for consumer portable electronics applications	N/A	N/A	TBD	Precommercial product available to qualified customers
MTI MicroFuel Cells	Mobion 30M	Micro/Portable	30w	DMFC	3.5x9.8x5.7"*	30w DMFC fuel cell	360 wh/kg	360 wh/kg	Yes	IQ 2007*
MTI MicroFuel Cells	Mobion 1M	Micro/Portable	1w	DMFC	1.3x3.7x6.0"*	1w DMFC fuel cell	TBD	TBD	Yes	IQ 2007*
Nuvera Fuel Cells	PowerFlow PFS-005	Portable, Stationary, Backup, APU	5 kWe	PEM	375x800x685mm	DC Power Module	56%	56%	Yes	Yes
Nuvera Fuel Cells	PowerFlow PFS-009	Portable, Stationary, Backup, APU	9 kWe	PEM	375x925x685mm	DC Power Module	56%	56%	Yes	Yes
Nuvera Fuel Cells	HDL-82	Transportation	82 kWe	PEM	150 liters	DC Power Module	58%	58%	Yes	Yes
Nuvera Fuel Cells	Forza RPM	Stationary, Backup,	125 kWe	PEM	3000 liters	DC Power Module	52%	52%	Yes	Yes

Nuvera Fuel Cells	HDL-82	Transportation	82 kWe	PEM	150 liters	DC Power Module	**58%**	**58%**	Yes	Yes
Plug Power Inc.	GenCore® 5T	Backup	5kw (net)	PEM	44"H x 26"W x 24" D	Direct hydrogen fueled DC Backup systems, designed specifically to replace or supplement valve regulated lead acid batteries (VRLA) in the Wireless Telecom Industry. Configurations include 24v, 48v and -48vdc. This product is also availible through State and Federal contract listings including GSA, NY-OGS, CA-CMAS and Tx- TXMAS.	N/A	N/A	2yrs	Yes
Plug Power Inc.	GenCore® 5U	Backup	5kw (net)	PEM	44"H x 26"W x 24" D	Direct hydrogen fueled DC Backup systems, designed for the extended back-up needs of Utility and UPS customers. Configurations include 48v Floating Ground, 120v Floating Ground and 120v Negative Ground. This product is also availible through State and Federal contract listings including GSA, NY-OGS, CA-CMAS and Tx- TXMAS.	N/A	N/A	2yrs	Yes
Relion	T-1000	Backup	600-1200 w	PEM	12.75"w x 19"d x 23.5"h	Backup power solution based on modular, hot-swappable cartridges for high reliability	N/A	N/A	2 yr	Yes
Relion	T-2000	Backup	600w - 2kw	PEM	19.75"w x 19.5"d x 23.5"h	Backup power solution based on modular, hot-swappable cartridges for high reliability	N/A	N/A	2 yr	Yes
Relion	I-1000	Backup	1kw	PEM	17.25"w x 25.12"d x 20.5"h	Backup power solution based on modular, hot-swappable cartridges for high reliability	N/A	N/A	2 yr	Yes
SFC Smart Fuel Cell	EFOY 600	Mobile / Backup	600 Wh/day	DMFC	43.5x20.0x27.6 cm	The EFOY 600 fuel cell is SFC's starter model for use in off-grid industrial applications like sensors, surveillance cameras, monitoring and measuring systems, audio & video equipment, and for leisure applications, eg motor homes, sailboat and cabins.	N/A	N/A	3 yrs	> 500 sales points and at 30 online stores
SFC Smart Fuel Cell	EFOY 1200	Mobile / Backup	1,200 Wh/day	DMFC	43.5x20.0x27.6 cm	The EFOY 1200 fuel cell is SFC's alround model for use in off-grid industrial applications like sensors, surveillance cameras, monitoring and measuring systems, audio & video equipment, and for leisure applications, eg motor homes, sailboat and yachts.	N/A	N/A	3 yrs	> 500 sales points and at 30 online stores
SFC Smart Fuel Cell	EFOY 1600	Mobile / Backup	1,600 Wh/day	DMFC	43.5x20.0x27.6 cm	The EFOY 1600 fuel cell is SFC's top model for use in off-grid industrial applications like sensors, surveillance cameras, monitoring and measuring systems, audio & video equipment, and for leisure applications, eg motor homes, sailboat and yachts.	N/A	N/A	3 yrs	> 500 sales points and at 30 online stores
Teledyne Energy Systems	Titan Series Hydrogen Generation Systems	Industrial, Transportation	2 to 60 nm3/hr	Alkaline Electrolysis	2 m3 to 12.5 m3	High reliability hydrogen and oxygen generation systems for use in industrial applications, refueling systems and laboratories.	N/A	N/A	Yes	Yes

Teledyne Energy Systems	Teledyne PEM Fuel Cells	Aerospace/Defense	100 Watts to 15 kW	PEM	Variable	High Efficiency, Hydrogen/Oxygen PEM FC systems for high altitude, subsea and space applications	N/A	N/A	None at present	Yes
Teledyne Energy Systems	Medusa Fuel Cell Test Stations	PEMFC, DMFC and SOFC Testing	Watts to 15 Kilowatts	PEM, DM, SO	Variable	High accuracy, NIST traceable test hardware for component and full stack testing	N/A	N/A	Yes	Yes
UltraCell	XX25	Micro/ Portable	25 W	RMFC	5.9" x 9.1" x 1.7"	The XX25 is a rugged, reformed methanol micro fuel cell system that extends the runtime of off-grid, portable electronics including laptops, surveillance, and communications equipment.	N/A	N/A	Yes	Yes
UTC Power	PureCellTM System Model 200	Stationary	200 kW	PAFC	18 x 10 x 10 feet	Cogeneration power plant with over 97% availability	Over 40%	90%	Yes. Several options	Yes
UTC Power	PureCellTM System Model 5	Backup	5 kW	PEM	21 x 17 x 28 inches (fits 19" or 23" rack)	High power density, expandable-scalable, reliable Backup power	Over 40%	40%	Yes. Several options	Demonstrators; Commercial offering in 2007
UTC Power	PureMotion™ 120 System	Transportation	120 kW	PEM	41 x 59 x 46 inches	Super efficient, quiet and emission free transportation fuel cell system. Revenue service began early in 2006; data is being evaluated	N/A	>46% @ 120 kW	Current offering is 4,000 hours	Yes

Fuel Cell Applications - 1
- Micro - Battery Replacement
- Portable - Mobile Electric Generation
- Backup - Emergency Power, Grid Parallel
- Stationary - Primary Power and Peak Shaving
- APU - Auxiliary Power Unit
- Transportation - Bus and light duty vehicle propulsion

Fuel Cell Configurations - 2
- AFC - Alkaline Fuel Cell
- DMFC - Direct Methanol Fuel Cell
- FFC - Formira Fuel Cell
- MCFC - Molten Carbonate Fuel Cell
- PAFC - Phosphoric Acid Fuel Cell
- PEM - Proton Exchange Membrane Fuel Cell
- RMFC - Reformed Methanol Fuel Cell
- SBHFC - Sodium Borohydride Fuel Cell
- SOFC - Solid Oxide Fuel Cell

Product is undergoing field testing*

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