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Eljas Aalto

Solar powered electric propulsion of a sailboat

Metropolia University of Applied Sciences

Bachelor of Engineering

Automotive engineering

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Production of oil and natural gas will begin decreasing after years 2020-2040. Nuclear fuel reserves with today's electricity generation and today's technology will last approximately 300 years. With theoretical or experimental technologies and today's electricity generation nuclear fuels can last up to 10 000 years. [3] It will take approximately 5 billion years for the sun to die. Until then we have plenty of time to harvest the power of the sun and keep our society running like it has been for the past 100 years. Climate change and the end of fossil fuels are an inevitable reason to make our energy sources sustainable. Making energy sustainable and renewable is a race where one with the most efficient and economical solution will win. Other than saving the world there is a massive market left to conquer by replacing fossil fuels with renewable solutions. This is a hard task since oil-based fuels are the biggest reasons for the growth of economy we have seen in the past 100 years, but to keep it the same and to avoid climate change caused natural disasters, it is very much necessary to make our energy sources sustainable.

This thesis will study and represent a way how a sailboat can be sustainably and economically powered by using an electric propulsion, batteries and solar photovoltaic (PV) technology. This thesis studies how this renewable solution will differ from a more traditional combustion engine solution and what are the advantages and disadvantages of this solution. This was a topical subject since I just bought a sailboat with a petrol engine which I wanted to replace with an electric motor. With a sailboat this is a relatively easy task since the main power to move the boat is wind, but you need some assistance when moving in and out of the port and when it doesn't wind.

Keywords	Sailboat, solar power, electric motor, renewable energy

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Tutkinto	insinööri (AMK)
Tutkinto-ohjelma	Ajoneuvo- ja kuljetustekniikka
Ammatillinen pääaine	Autosähkötekniikka
Ohjaajat	Lehtori Vesa Linja-aho

Öljyn ja maakaasun tuotanto alkaa hiipua vuosina 2020–2040. Ydinpolttoainevarat riittävät sähköntuotantoon vielä noin 300 vuoden ajan. Teoreettisin ja kokeellisin teknologioin ydinpolttoaineet riittävät vielä 10 000 vuoden ajan. Aurinko kuolee arviolta 5 miljardin vuoden kuluttua. Sitä ennen meillä on hyvin aikaa kerätä auringon energiaa ja pitää yhteiskuntamme kehityksen samalla tasolla, kuin se on ollut viimeiset 100 vuotta. Ilmastonmuutos ja fossiilisten polttoaineiden loppuminen ovat välttämättömiä syitä muuttaa energianlähteemme kestäviksi. Energianlähteiden muuttaminen kestäviksi ja uusiutuviksi on kisa, jossa tehokkain ja taloudellisin ratkaisu voittaa. Maailman pelastamisen lisäksi, fossiilisten polttoaineiden korvaaminen on markkina, jossa on vielä paljon valloitettavaa. Tämä on hankala tehtävä, sillä öljypohjaiset polttoaineet ovat pääosin vastuussa maailmantalouden tähänastisesta kasvusta viimeisen sadan vuoden aikana. Pitääksemme kasvun samalla tasolla ja välttääksemme ilmastonmuutoksesta aiheutuvat luonnonkatastrofit, on tämä muutos välttämätön.

Tässä opinnäytetyössä selvitetään, kuinka purjevene voidaan varustaa kestävällä ja taloudellisella tavalla sähkömoottorilla, akustolla ja aurinkopaneelijärjestelmällä ja tutkitaan, kuinka tämä uusiutuvaa energiaa hyödyntävä ratkaisu eroaa tavanomaisesta polttomoottorijärjestelmästä ja mitkä ovat tämän ratkaisun hyvät ja huonot puolet. Aihe on ajankohtainen, sillä ostin juuri purjeveneen ja halusin vaihtaa sen polttomoottorin sähköiseen. Purjeveneen kanssa tämä on verrattain helppo tehtävä, sillä veneen päävoimanlähde on tuuli, mutta moottoria tarvitaan ajoin veneen ajamisessa satamaan ja satamasta pois sekä kun ei tuule.

Avainsanat	Purjevene, aurinkoenergia, sähkömoottori, uusiutuvat energianlähteet

Contents

List of Abbreviations

PV	Photo Voltaic, is the conversion of light into electrical energy using semiconducting materials that produce electric current when exposed to light.
PWM	Pulse width modulation.
kn	Knots. A measure for speed, used in maritime and aviation.

1 Introduction

Production of oil and natural gas will begin decreasing after years 2020-2040. [4, p.3] Nuclear fuel reserves with today's electricity generation and today's technology will last approximately 300 years. With theoretical or experimental technologies and today's electricity generation nuclear fuels can last up to 10 000 years. [3] It will take approximately 5 billion years for the sun to die. Hope we as humans or a species that evolves from us will reach other stars before that. Until then we have plenty of time to harvest the power of the sun and keep our society running like it has been for the past 100 years. Climate change and the end of fossil fuels are an inevitable reason to make our energy sources sustainable. Making energy sustainable and renewable is a race where one with the most efficient and economical solution will win. Other than saving the world there is a massive market left to conquer by replacing fossil fuels with renewable solutions. This is a hard task since oil-based fuels are the biggest reasons for the growth of economy we have seen in the past 100 years, but to keep it the same and to avoid climate change caused natural disasters, it is very much necessary to make our energy sources sustainable.

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2 Solar Energy

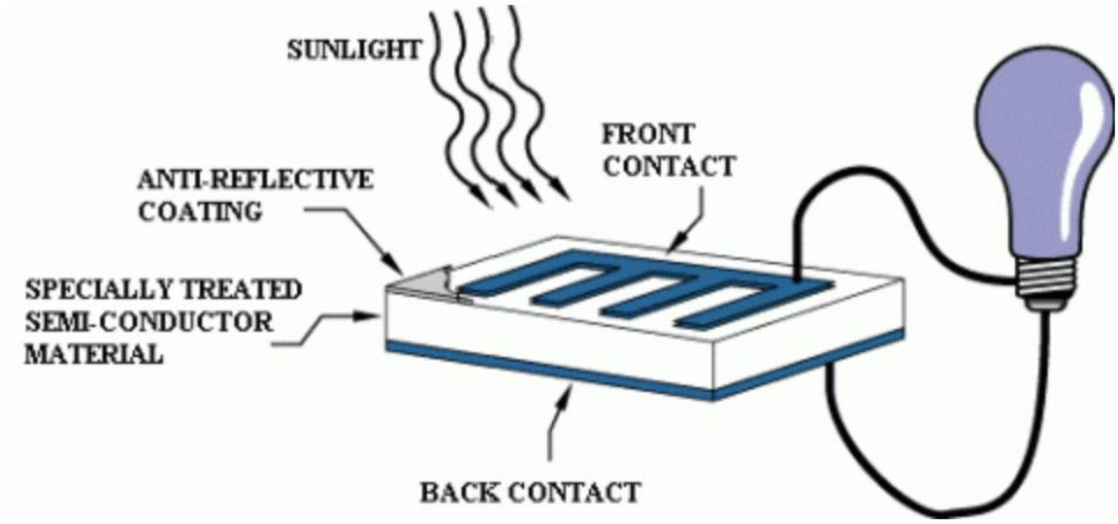
Sun radiation is the basis of renewable energy. The radiation of the sun mostly consists of infrared radiation (heat), luminous light and ultraviolet radiation. Infrared rays generate wind, waves, rain, and of course heat. Life on earth would not be possible without sun. Sun is responsible for the fossil fuels also. It is the energy that gave life to the now fossilized organic materials we pump out of the ground known as oil. Why oil cannot be called renewable is because it has formed over millions of years and it now has been consumed almost completely in 200 years.

The average solar flux intercepting the earth is 1.37 kW/m^2. Part of this is scattered and absorbed by the clouds and atmosphere. Density of the flux varies depending on the location on earth due to earths curvature. Average flux hitting the earth's surface is approximately 174.7 W/m^2, leaving a total of 89 300 TW of sun's radiation energy hitting the earth's surface all the time. Energy consumption on earth in 2016 was roughly 142 000 TWh. [5] That is roughly one and a half hours of sunlight hitting earth, covering all of human's energy consumption. [1, p.10]

There are many ways of capturing sun's energy. Most common ones we see today are photovoltaic cells, solar heating and concentrated solar power. Also, wind and wave generators capture sun's energy because those are reliant on the wind which is caused by the sun. Those methods listed above are all used for example off-grid solutions to power houses or boats or to reduce the need of grid power and to lower electricity bill. These are all products of the 89 300 TW of sun's energy hitting the earth all the time.

2.1 Photovoltaic technology

The photoelectric effect was first discovered by a French physicist, Edmund Bequerel, in 1839. What Edmund found was that certain materials, when exposed to light would produce a small electric current. Today's photovoltaic technology is based on Albert Einstein's Nobel prize winning description of the nature of light and the photoelectric effect. The first photovoltaic module was built by Bell Laboratories in 1954. It was then billed as a solar battery but was too expensive to gain widespread use. In the 1960's the space industry began to make first serious use for the technology to provide power aboard a spacecraft. [2]



Picture 1. Function of photovoltaic cell [2]

The picture above demonstrates the function of a basic photovoltaic cell, also called a solar cell. Solar cells are mostly made out of semiconducting materials such as silicon. This silicon is made into a thin wafer and treated specially to make form an electric field, positive on the other side and negative on the other. When light hits the silicon, it releases electrons. Attaching electrical conductors between positive and negative side of the cell make an electric circuit. This electric circuit can be used to capture the current of electrons and to power a load, such as a light or a battery.

Solar cells are arranged to make modules and the modules are arranged to make solar arrays, also called solar panels. These cells, modules and panels often are designed to supply electricity a at certain voltage. Therefore, the current produced is directly dependent on the light striking the cells. Photovoltaic modules and arrays produce a direct-current (DC) voltage. Multiple modules can be connected together to make a larger solar panel. The larger the area of modules or panels are, more electrical power will be produced.

2.2 Economics of photovoltaic technology

The price of solar panels has been in a descendent trend since the first Solar battery by Bell Laboratories. Yet the price is still relatively high and installations for private houses for example take approximately 6-20 years before the investment has paid itself back. This is due to the relatively low price of electricity and has led to that solar panels have mostly been used in cases where there is no electricity grid available or it would be too expensive to build the infrastructure needed for joining the grid. Only in the recent years when the price of solar panels has dropped low enough the trend for installing them on the roofs and surfaces of grid joined buildings have been going up. One other reason for this growing trend is probably peoples concern for climate and the will to do something for it's good. The growing trend of installations is good for the business and also for the customers buying these panels. With bigger production volumes the price tends to drop and that is what has happened and is expected to continue the same.

In current conditions photovoltaic technology will most likely return the money invested though, in such a long time it has not yet gained a role as a mainstream power source for most homes and businesses. Where it has gained a major ground is powering off-grid solutions like cottages or boats. Actually, you can see solar cells in many kinds of boats from new to old, motor- to sail boats and in electric and combustion engine powered boats. Solar panels charging batteries allow boat users to use electricity while the engine or generator isn't running thus making living on the boat much more pleasant. Solar panels also charge batteries while the user is away. This allows boat owners to leave loads like security alarms or whatever without worrying about the batteries to run out of power.

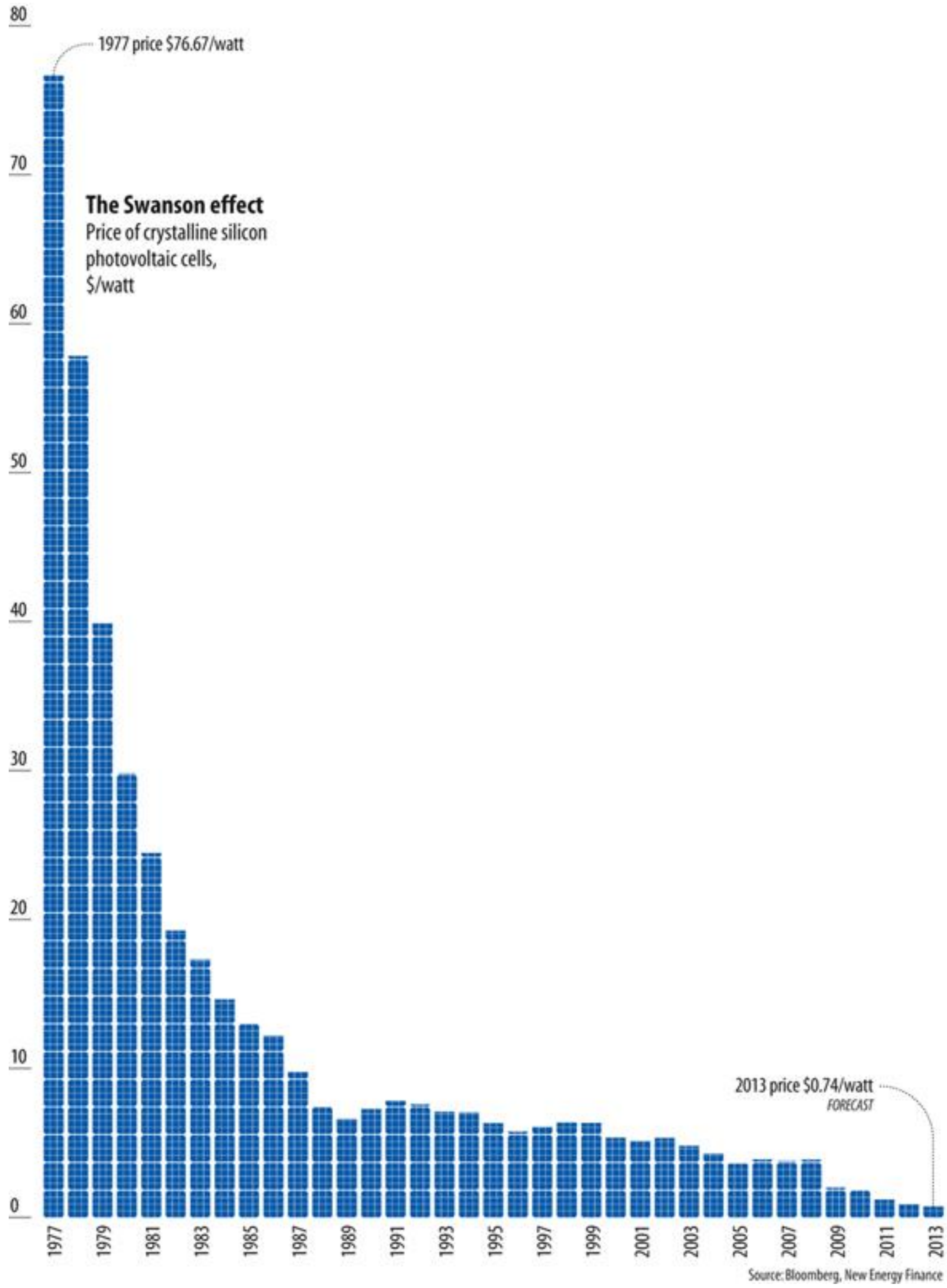


Figure 1. Price of photovoltaic silicon cells USD/Watt [6]

3 Powering the sailboat

The boat in question is a 6.4m long 1000 kg Finn Express 64 made in 1983. I bought the boat with a friend of mine in the beginning of the summer 2019 with a relatively big 15 hp Suzuki four-stroke petrol engine. The engine was way over scaled for the boat but was in good condition. Since internal combustion engines like this require service every year and still are not the most reliable products and they also make noise, pollute, vibrate and require gasoline to be bought and fueled to the tank, I decided it is a good idea to search for an alternative option, in this case an electric motor.

Electric motors have been a growing trend in the boat market but have been mostly marketed and bought for small boats like row boats or as an assisting motor used in fishing for bigger boats. There are companies like Oceanvolt that manufactures small power electric propulsion systems for bigger sailboats, motorboats and vessels such as a harbor ferry. Those systems are very high quality and well designed. However, they are too big, powerful and expensive for this project.

In this case the motor would have to move the boat in and out of the port and during times when it doesn't wind, or the wind is against the way of heading. With a sailboat the main propulsion is the sails, which harness the wind to move the boat. Sailing is a great way of enjoying the nature and it doesn't pollute in any way. When sailing you are very much dependent on the weather situations especially when compared to motor boating. Depending on your sailboat there is approximately 30-50-degree area upwind you can't sail. Also, if the wind does not blow, the boat won't move. These are easy to take note and prepare your route and time of travel to make the trip fluent. Where it comes tricky is the narrow spaces, which you can find on almost any route in the Archipelago. A narrow space between islands is a place where for example the trees or ground formations can cause the windspeed to drop near zero or make turbulent streams so that the wind direction quickly changes against your heading. Also, when maneuvering in and out of the port you need a motor to give the boat speed in the direction wanted. This is why it is necessary to have a propulsion system in addition to the sails.

3.1 Requirements of the propulsion system

Since the main propulsion are the sails, and a motor is needed only time to time, a big battery pack would not be needed. Based on our own experience, two hours of run time should be well enough for one to three days of use. Batteries would charge always when the sun hits the PV system and when in port a charger could be used to charge the batteries over night from 230 VAC source. The PV system should be as big as possible, but limitations mostly consist of the lack of area. There are also some consumers aboard including sonar/navigator/speedometer system by Raymarine and lighting. These won’t consume much but will be calculated and taken into account.

3.1.1 Motor

The boat’s former 15 horsepower petrol engine was, as mentioned earlier, way over sized and most of its power was never used. Due to the sailboats hydrodynamical features it would require power very much from a motor to propel the boat to the speed that it achieves with the sails. The sails are attached to the mast which together with the keel are located in the middle of the boat. The mast and the keel are two main parts where the thrust of wind is linked to the boat. The hull of the boat is designed in a way that the thrust hits the boat via mast and keel. The motor in the back easily pushes the boat but if pushed hard enough the boat starts to raise its front but will never plane. The boats top speed approximately 10kn which is achieved with the sails and a small motor will not help at these speeds. Since the motor is only needed when moving in and out of the port and when moving up- or without wind, it is not necessary for the motor to deliver much power. A power to move the boat with a speed of 2–3 kn should be very much enough and the motor should be powerful enough to move the boat up to 12 m/s upwind.

Hydrodynamical features of this sailboat were not to be found which is likely due to the rarity of this model. Since the drag of the hull was not known, the exact power needed could not be calculated, instead the size of the motor must be defined by motor dealers guideline values and then tested in practice. Many other same sized sail boats use a small petrol engine designed for a rowing boat. These engines power usually vary between 1-5 horsepower. Not many electric motors are sold with a figure of their peak horsepower like petrol engines are. Instead, electric boat motor manufacturers use lbs. of thrust the motor produces as a figure to represent strength and to categorize different models. This figure of lbs. is not relative to power and thus cannot be calculated directly. Manufacturers and dealers have guideline values for which motor fits for what sized boat and this is good information when selecting the motor. Electric motor manufacturers often tell the maximum electrical power the motor consumes. This is very relevant value and can be used to estimate the delivered power of the motor when the efficiency coefficient is taken into account. This peak electrical power is also very useful when the size and requirements of the accumulator are calculated.

Looking at the market of boat electric motors there were many to fit our purposes, but one was chosen to be the first candidate. It is a Chinese made but re-packed and marked in Finland, Neraus NRS-86L. The motor uses 24 V voltage and should provide a thrust of 86 lbs. Maximum intake power is 1152 W. There are no precise formulas to turn this information available into output power, but if the intake power is calculated with an approximated efficiency of 90 % it should deliver at least one kW of power which should be enough to move the boat for the speed of couple knots. Actual performance is not known before the motor and accumulator are put to test.

3.1.2 Accumulator

The accumulator or batteries should have enough energy to move the boat for at least two hours and power the necessary lighting for one night. The motor of choice is to consume electrical power approximately 1.1 kWh if and when used in full power. Full power from the motor will lead to a higher speed but a much higher energy consumption. If we assume that motor is not used at its full power for the whole time but at variable speeds and it would approximately consume 1 kWh of energy, we would need a battery of two kWh plus the energy required for the lighting and sonar.

The lighting consists of three 5 W lights so a power they need per 12 hour dark time is 5 W x 3 x 12 h = 180 Wh. The sonar uses power approximately 50 W though it is not necessary to use for the whole time when cruising so we can assume it is used for 4 h in one day making 200 Wh in total. All together is 2.38 kWh in one day with two hours of near full power motor use, one night of lighting and 4 hours of sonar use. This said the accumulator should hold a charge of at least 2.4 kWh just to be sure and to avoid harmful over discharge.

Thus, the motor of choice is 24 V and due to the good price/performance ratio we are going to use lead-acid batteries, we are going to need a paired amount of 12 V batteries connected in series to make a 24 V system. With these requirements a couple of 110 Ah 12 V lead-acid batteries were chosen to be used. These batteries connected in series are equal to 2.64 kWh of electrical energy which should be very well enough.

The weight of the batteries and electric motor is a few kilograms less than the old petrol motor and fuel tank. Since the batteries are installed under the waterline on the bottom of the boat their weight slightly helps balance the boat.

3.1.3 Photovoltaic system

When it comes to solar power, more power the better. Yet one thing is critical in a sailboat – space. There is not too much space for the solar panel or panels and that will lead us to a compromise. The solar panels are for charging the boat on the go and in places where there is no electrical grid to connect. In most harbors and in the boats home harbor, there is electrical grid. But especially on the move solar panels can act as a range extender for the electric motor and batteries. On the deck of the boat almost all the space is either for sailing gear or space to step on. Anyway, it is hard to find a large flat area on the deck meaning we have two options; find solar panels that bend and can be stepped on, or place them outside of the boat.

Solar panels power varies between manufacturers and models but not much. It is easy to estimate that, with technology available today 1 m_2 solar panel provides maximum power of roughly 200 W. Usually more expensive the panels are, more power they provide. Though, not much and usually higher price refers to better quality overall making the panel withstand higher wear or weather conditions.

On the boat there is space in the middle for roughly 500 mm x 500 mm sized solar panel and on the back of the boat a space for roughly 1 m_2 solar panel but in the back, there is a problem that is support. Since there is a wall and handrail but not any kind of flat surface to support the panel on, heavy panels cannot be installed. Although the panels must be rigid to support themselves so a smaller panel must be used.

Solar panels require a charging controller for charging the batteries. Nature of this controller is dependent on how much power solar panels can provide and what kind of batteries are used. For this project we use 24 volt battery system, which has to be noted when selecting the controller.

The price of single, hard and framed panels in Finland vary between 0.50 €/W to 1 €/W. Durable panels, designed to bend cost from 1.80 €/W to 4 €/W. Price per Watt usually drops when moving towards bigger panels. This is likely due to the time used in manufacturing per panel.

3.2 Design of the system

Parts of this system were chosen with a few criteria; 1. is that they must function as intended 2. is that they are easy and reliable to use and 3. that they don’t cost more than 1000 € which was the price the old petrol motor was sold. So far, all these criteria all filled.

3.2.1 Photovoltaic system

After searching the market, the lowest price was found in panels that ship from China, but since that would have taken too much time, the photovoltaic system was to be searched in Finland.

Where I ended up was a full package including 80 W solar panel, connectors, controller and a wall support for solar panel. The package cost only 169 € in total and more solar panels can be added into the controller so the system can be scaled up if necessary. The wall support was partially used to make a stand for the panel.

Picture 2. Solar panel and motor installed on the boat

This 80 watt panel is aluminum framed, multicrystalline silicon and weights roughly 7 kg. It is as big as it is possible to mount to the back of the boat and now sits there nicely without being in the way or causing any harm to its surroundings. How much the PV system delivers power in one day is mostly due to the weather. During summer, if the weather is sunny all day in southern Finland, the sun should shine between 14 to 20 hours in one day. Though this yet doesn't help but estimate how much energy will be generated.

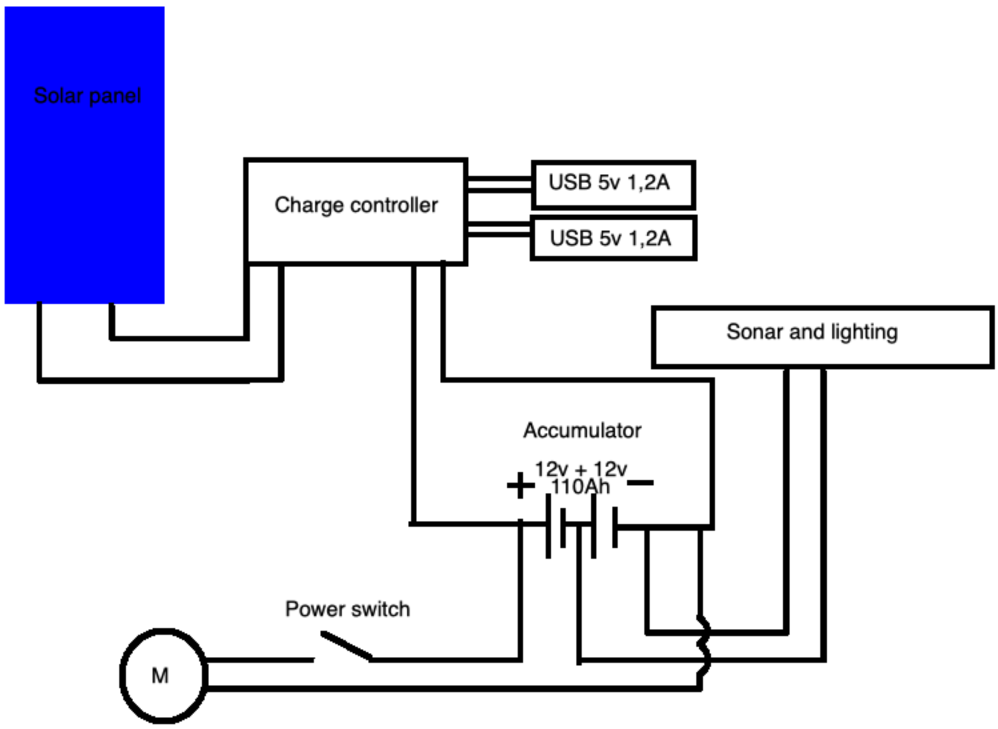
One factor that varies also is the boats and the panels angle relative to the sun. Also, what can cause a shadow over the panel is the mast and sails. Panel should provide power on a cloudy day also, but not at all as much as on a sunny day. One option would be to tilt the panel facing the sun at all times, but when sailing, direction of the boat may vary quite often and then the risk for the panel to face into wrong direction would rise. There are also automatic systems that track the sun and then tilt the panel automatically, but those consume power, cost more and often require more space. This is why in this case the panel is installed facing upwards, and so it should most likely provide maximum energy during a day.

Since the panel will not be facing directly towards the sun all day and also weather conditions may vary it is hard to estimate daily energy generation, but this is a factor that will be measured and explained later in this thesis.

The controller was placed near the battery in the boat in a clean and relatively dry location. The controller can show many values. Most useful information is, it tells the battery voltage and state of charge. It also tells how much the PV system is providing current, voltage and power. Also, it tells how many kWh it has charged since last reset. The controller functions with PWM (pulse width modulation) meaning it cuts the charge multiple times per second in order to keep the charging voltage suitable for the battery.

Connectors of the solar panel are MC4 type. They are commonly used with PV systems and don't require any tools. They are also helpful if the panel has to be moved, the connectors are easily and reliably opened and closed.

4 Outcome and results



Picture 3. Electrical diagram of the PV and propulsion system

Outcome was better than expected. The motor can be used for good travel speed of 2.5 knots in it's lowest speed position 1/5 consuming roughly 400 watts, making battery last for six hours of drive on motor and the solar panels providing more power when the sun is shining.

On a sunny day the panel generated roughly 700 Wh of energy, giving almost two hours of extra run time. This is also very helpful on longer journeys when there is no connection to the electric grid. On cloudy days the panel did not really charge at all and this has to be taken into account when going for longer journeys. As usual the weather is a crucial factor when sailing, so this doesn't make a big difference, but has to be taken into account.

A boat storing electrical energy into its batteries and using a motor to run, has a very similar routines as with an electric car for example. When moving around and stopping on the way you want to find places with electricity to charge. Though, with a sailboat the main power is wind pushing the sails and thus the journey usually doesn't stop if you run out of battery. Also, with the solar panel and charging system onboard the need for connecting to electric grid is degreased, helping to plan journey and to travel longer. In a way this solution could be called as a hybrid of electric propulsion and wind power. It used to be a hybrid between petrol engine propulsion and wind, but with this upgrade it has some features, comforts and in a way, new challenges.

4.2 Comparison

4.2.1 Range and speed

The range in day to day use has degreased with the upgrade. Depending on the weather and charge from PV system, using only the motor, the boat can move between 2,5 h to 8 hours in a day with a speed of 2.5-4 knots extending the maximum range to almost 45 kilometers. With the older petrol engine system, the range and travel speed were much higher (5-10 knots and depending on how much fuel was loaded in canisters, the boat could have traveled up to 150 kilometers with the engine used only. Though, when it is not possible to join the electric grid or to stop for fuel, the PV system provides power every time the sun is shining and thus making it possible to travel as far as food and water resources can last for the crew onboard.

The electric motor, accumulator and the PV system in a sense of being the secondary power unit with the sails has turned out to be very clever, since the motor really is used mostly when moving in and out of the port, when it is necessary to move upwind or when it doesn’t wind. In our regular use, the motor is run approximately between two minutes to 1 hour a day, making the system very good to our use. Also, the motor can be used with the sails, on lower winds, providing more speed and making the handling much easier and stress free.

4.2.2 Maintenance and reliability

This is where the electric motor shines. There is no need for service with this electric motor. The motor is located under water and its rotor shaft is directly mounted to the propeller leaving all gears away. Near handle is all the power electronics, that according to manufacturer are weather resistant. The electric motor of choice is not a very popular one and any user information of its reliability is not known, but it has a two-year warranty which gives some expectations that the motor should last.

In the petrol engine the motor and the assisting systems are located near the handle and a gear driven shaft connects to the propeller under water. With the petrol motor and its gear and shafts, two different oils are meant to be changed every autumn after the driving season. This, of course is a job that requires time, money and new oil.

Whereas with the electric propulsion system only thing that should be done every autumn is to charge the accumulator full, since it is made of lead acid batteries and they are at most stable point when they are charged full. During winter the batteries can be charged a couple of times to make sure the batteries are full and hasn’t been discharged themselves. Other option is to keep them connected to a so-called smart charger aka a computer-controlled charger that can quit the charge in case of overcharge and keep the batteries in balance. This is a kind of charger that is now in use on the boat and is used when charged from the electric grid.

Service of the PV system is easy. The panel has to stay clean and otherwise it should last quite long. This PV system of choice is not very expensive, so only time will tell how long it will last, but since it is basically a rather simple device, the expectations are quite high.

The accumulator is made of two lead acid batteries that can be filled with distilled water and so extend their lifetime. Anyway, the batteries have two-year warranty and usually these kind of batteries last three to ten years before they have to be replaced.

4.2.3 Comfort and use

In practice, the electric motor doesn’t make a sound. The biggest sound comes from the water passing thru the boat, which has to happen due the boat to move. This is a completely different feeling compared to the combustion engine which makes usually a rather loud noise and thus making the travel far less pleasant. Whereas pleasure is the main thing anyone goes to sail. The electric motor doesn’t need any starting up, any choke to help it start. The electric motor switches on from an easily turned switch and doesn’t really vibrate. In a combustion engine all these examples are present an making it obviously much less pleasant to use. Before, with the old petrol engine you always had to worry if the engine starts when entering the port for example. Now, you just turn the handle and maneuvering has never felt so easy. The silence, reliability and the fact that the motor doesn’t smell makes this solution by far more pleasant compared to the elder combustion engine.

4.2.4 Economics

The costs of this new electric propulsion system and PV system were all covered with the retail price of the old motor. The petrol engine was sold for 1000 €. New motor cost 210 €. The two batteries cost 200 € and the charger cost 100 €. PV system cost 170 €. Cables, connectors and fastening gear cost roughly 40 €. Making in total 720 €. Every time the electric motor is used there is no need to pay since the electricity generated from the PV system is free and electricity from the grid is included with the harbor costs.

A new petrol engine with an equivalent power of 1.5 horsepower (1.2 kW) with a fuel tank cost roughly 1100 €. This said, powering a sailboat with an electric motor instead of a combustion engine is not just ecologically friendly, easier and stress free, it is also an economic solution.

4.3 Applicability

Similar system is easily duplicated into similar sized boats and other vessels. Since there are so many different boats on the market this system cannot be replicated directly but most of the parts fit with minor adjustments related to fixing the parts to the boat. What varies most between boats is their size in weight and volume thus requiring different solutions in propulsion power and accumulator capacity. The system in this thesis is very powerful compared to for example rowing boats where these kind of hand steered motors are usually used. The motor in this system has a power of approximately 1 kW and the boat weighting 1 ton with cargo and passengers added to its weight, this system is very close to as big as can be used with similar type motors. If the boat was over 10 % bigger it would require a bigger motor, bigger accumulator and as mentioned earlier, bigger the PV system is the better.

The system in this thesis is suitable for vessels approximately the same size or smaller than the boat it was now installed. Moving to bigger boats, a barrier would soon be reached, and speed and handling would be on a level that would not be safe especially in hard wind conditions. This system is designed for sailboat use where the main propulsion power is sails and wind. This system is, as concluded earlier, good in sail boats replacing the combustion engine, but would not be suitable for replacing a motorboats engine, where this solution would be too weak. A low speed motor or a rowing boat is where this system could also be easily applied and would work perfectly for example in fishing.

In conclusion if a boat weights under one ton and there is no need to travel further than 45 kilometers and maximum speed of 3-5 kn is enough, then this would likely be the smartest option. Any boat that uses 1-1.5 horsepower motor and has room to fit this system could be a candidate to use this system instead of the fossil fuel using and noisy combustion engine.

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