Energy management: Comfort without a generator

We have been living mainly on our boat, a Berckemeyer BM48 made of aluminum, for 6 years and have sailed from Europe to New Zealand and have had numerous experiences and surprises along the way. In the following text we would like to give you an overview of our experiences and some suggestions and ideas for your own electrical system.

Basics

When building the ship, one of the key points was that the energy concept should work without a diesel generator. Such generators not only cause costs during construction, but also involve considerable weight and space requirements. Not only that, but their operation is also associated with vibrations and a considerable amount of noise for your own boat and for the neighbors in the anchorage. Few things can be more disturbing in a peaceful anchorage than the humming and splashing of your neighbor's generator.

The amount of maintenance required should also not be underestimated. If an oil change is due every 250 hours and the generator runs for 3 hours a day, it means having to contort yourself every 3 months and carry out the service under the generator's soundproof cover. Problems with non-functioning generators were also a frequent topic of conversation between sailors in the harbors and anchorages during our half-circumnavigation. This does not even take into account ecological aspects such as carbon dioxide emissions.

The aim should therefore be to achieve maximum quality of life without the use of a diesel generator. For reasons of reliability, the on-board electrical system has a classic design without a bus system and is 12 V. It should also be mentioned that the boat is mainly sailed by just two people. This has an impact on the amount of water to be produced by the watermaker as well as on the amount of drinks to be cooled down and thus on the energy balance. To make matters worse, the effectiveness of cooling devices suffers in the high temperatures in the tropics.

Electricity generation

Solar

By far the most important element is the solar power system (Fig. 2). Over the years, this has become increasingly clear and the surface area of the panels has been expanded. When the ship was built, there were 3 glued-on panels of 69 Wp each on the fixed dockhouse. Two years later, 4 more panels with a total of 192 Wp were added on the superstructure in front of the traveler and 3 years ago, 2 fold-out fixed solar panels with 160 Wp each were added on the forward extended tubes of the pushpit. All panels are protected against mutual discharge with diodes and connected to the on-board power supply via two Votronic Mpp controllers.

Fig. 2 left: Solar panels glued to the fixed dockhouse and the superstructure in front of the traveler
right: one of the fold-out solar panels on the forward extended pushpit

So there is about 400 Wp on deck and 320 Wp at the rail. Nevertheless, the modules on the rail contribute more to the charge (about 55%). The reason for this is that two to three of the panels on deck are practically always shaded by the main boom and that the panels mounted on the rail are better ventilated (=cooled), which increases the power output.

So how much yield do the solar panels produce? During the last Atlantic crossing and the subsequent time at anchor in the southern Windward Islands, the power output was recorded. The results are shown in Figure 3, separately for the 7 panels glued to the deck and the 2 hinged panels on the rail. Under sail, the average production was 139 Ah with 173 Ah as maximum and 103 Ah as minimum. On the leg to the Cape Verde Islands, the yield was lower. The reasons for this are the more southerly course, where the panels are inevitably shaded more, as well as the shorter days and the lower horizon distance of the sun in the more northerly latitudes near the Canary Islands. At anchor –without any sails– and at 12° to 13° north latitude, the yield is even

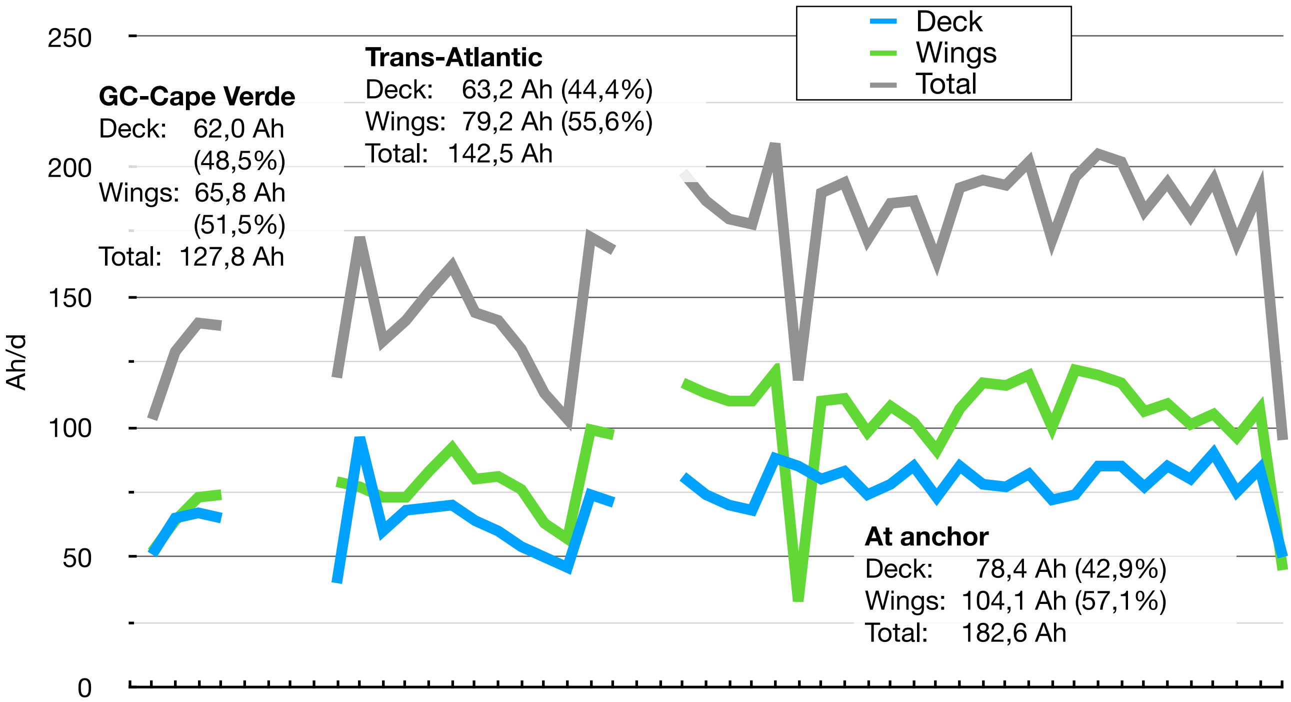

Fig 3 Real-world data on the yield of the solar system described in the context of a transatlantic voyage from the Canary Islands to the southern Caribbean, divided into the two segments of the transatlantic voyage and approx. one month at anchor in various bays.

better with an average of 183 Ah. Here the maximum was 209 Ah and the minimum 95 Ah. The possible yields are probably even higher, as the controllers switch off when the batteries are full, which is inevitable in this *real-world* description.

This means that the solar system easily saves more than 3 hours of charging with the engine at 60 A, and even with a high-performance charging system you still save 1.5 hours of engine charging per day. Converted to the usual kilowatt hours in a domestic household, the yield is 1.6 kWh to 2.2 kWh per day. Incidentally, the solar yield during the marina stays in Mindelo/Cape Verde and St. Georges/Grenada was still 90 Ah to 95 Ah per day even though the shore connection was plugged in and the panels on the rail were folded down.

What effect does bad weather have? As can be seen in Fig. 3, the minimum yield is still almost 100 Ah or 50% of the average yield. Although it rained a lot that day and it was always 8/8 cloudy, the light intensity is still significantly higher than on a November day in northern Germany. As a rule, any shortfall in battery charge can be made up on the next sunny day. There are also a number of flexible consumption times (making water, baking bread; see below) that can be avoided on a day with a low solar yield.

On the subject of durability: It is often advertised that solar panels have no moving parts and last almost forever. The panels glued to the deck have almost all quit to work after 10 years. This is not so noticeable at first; a lower yield is initially blamed on a few clouds in the sky. It therefore makes sense to test the panels with a certain regularity. For this purpose, it is very advantageous if the solar controller/regulator has a display that shows the current Ampere. Under otherwise constant conditions, an assistant places a towel on the various panels one after the other and the reduction in the displayed solar current is observed.

To summarize on the subject of solar panels: You can't have enough! No noise and practically no work or maintenance, which makes this technology highly attractive for sailors, especially in southern waters. The only problem on monohulls is accommodating the desired area. Many blue water sailors have elaborate structures attached to the stern of their boats for this reason and one sometimes wonders how these surfaces perform in seriously bad weather. Another advantage is that the panels do their job even when you are away and unattended. This means that shore excursions lasting several days with the refrigerator running are possible without the boat being connected to shore power, e.g. at anchor or at the mooring. Or even in the marina if there are power cuts, which we have experienced in less developed areas of the world.

Wind

A Superwind 350 is mounted on the gantry at the rear. Since the modified wings have significantly reduced the noise level, the noise development is acceptable, but still somewhat disturbing, especially in relation to the noiseless solar panels. The yield is negligible below 15 kn of relative wind. It is worthwhile at anchor from 4 Bft, as well as when sailing from 6 Bft from astern or when sailing upwind, although most long-distance sailors like to avoid the latter. We have rarely been able to generate more than 10 A charging current with wind for a longer period of time. However, the wind generator has two advantages that should not be underestimated: It works day and night and 5 A over 24 hours is also 120 Ah. And the second advantage is that the wind generator often works complementary to the solar panel, i.e. there is often wind, especially in bad weather when there is hardly any solar power. Nevertheless, for trips to areas with good weather (Mediterranean and tropics), two additional solar panels - if they can be accommodated - seem to make more sense than a wind generator. The situation is

Fig. 4 Wind generator on the gantry (stern bar)

different at higher latitudes.

Alternator on the main engine

For the largest possible charging capacity, a second, large alternator on the engine would be ideal. Large alternators have fewer thermal problems, need to be regulated down less and are more reliable overall. In addition, the remaining original alternator on the engine provides a certain degree of redundancy. Unfortunately, it was impossible to fit a second alternator in the engine compartment for space reasons. As an alternative, a small-body high-power 200 A alternator from Balmar was used in conjunction with a conversion kit for the Yanmar engine (4JH4TE) with a 10-grove ribbed belt and tensioner for the belt. Any effects on the engine supplier's warranty must be taken into account.

Fig. 5: Balmar alternator (red, 12 V/200 A) with new belt pulleys for flat multigroove belts (blue) and tensioning device (also blue)

Very important are the temperature sensors on the alternator and the battery, as well as a corresponding external controller. An ARS MC614 from Balmar was used, and for the last two years it was exchanged for a Wakespeed WS500, which regulates even better with a shunt directly in front of the battery, as it can differentiate between charging current into the battery and consumer current. A large AGM battery bank or a lithium battery can draw so much charging current that it heats up the alternator to the point of destruction, unless the temperature sensor on the alternator in conjunction with the programming of the controller limits the charging current. For better cooling, the fresh air supply to the engine compartment is routed directly to the alternator using a flexible ventilation pipe. With such a set-up, the above-mentioned 200 A alternator initially generates approx. 150 A and in the medium term, when the current limitation kicks in for thermal reasons, still 90 A to 130 A.

On the subject of charging current distribution, it has become clear over the years that there is only one sensible solution: The alternator and the voltage sensor of the regulator are connected directly to the service battery bank. The engine battery is then charged by a B2B charger. All previous attempts with diode or FET charge distributors had serious disadvantages and resulted in either one battery bank not being fully charged and coming to a premature end due to sulphation, or the other battery bank being overcharged and thus coming to a premature end. The effective charge depends on 0.1 V more or less and the voltage drop in the cables to the battery alone can lead to problems. For example, a charging current of 100 A in the service battery would perhaps result in a voltage drop of 0.3 V, but as the starter battery is full again after 5 minutes, only a minimal current flows there, causing practically no voltage drop. As a result, the starter battery in the example is charged with 0.3 V more, although it should actually already be in the float stage and should receive approx. 1 V less. With the separate B2B charger, the starter battery receives exactly the charge it needs, regardless of the state of charge of the service battery. Another advantage of this method is that different battery technologies can be used for the starter and service battery (e.g. gel for the service battery and conventional plates for the starter battery)

Shore power

Even though we mainly live "at anchor", it does happen that we are sometimes moored in a marina and this may be for a longer period of time, for example when wintering in the Mediterranean or - as in our case - during the lockdown in New Zealand. We use a Victron Phoenix multiplus with 80 A charging capacity and 2000 W inverter power; more on the latter below. It is important that the charger can cope with different AC voltages and frequencies. In large parts of America and many islands in the Caribbean and Pacific, 115 V at 60 Hz is common. As our boat is made of aluminum, it also made sense to install an isolation transformer for corrosion protection reasons. This can be switched to ensures that the charger works at 115 V, but it also allows that all 230 V consumers on board work with shore power. The amperage of the charger is not critical, as the batteries are always recharged within 12 hours using shore power.

Portable Generator

A mobile, gasoline-powered Honda EU20i generator with 1.6 kW continuous output was planned to operate the washing machine at the anchorage and as a back-up in case the charging option via the main engine should fail. It turned out that both applications tend not to occur or occur extremely rarely. The noise is disturbing both for your own ears and for any neighbors, even if this model has a relatively moderate noise level.

To ensure that the generator remains operational, the engine must also be serviced regularly (oil change) and the gasoline must be preserved with a stabilizer, at least if it contains organic components. Gasoline purchased in Germany has a target life of only 3 months. Fortunately, in most areas where long-distance sailors live, ethanol is used for other purposes than diluting gasoline.

Fig. 6: Mobile generator for emergencies

Energy consumption

Listed in order of relevance:

The refrigerator or, on many yachts, the fridge**s** are among the most relevant consumers. A fixed value cannot be specified, as it depends heavily on the ambient temperature. Consumption is proportional to the difference between the ambient temperature and the internal temperature of the refrigerator. At a temperature of 30°, a refrigerator quickly consumes twice the amount of electricity (30°-10° vs. 20°-10°). In one of our two refrigerators, the cooling air is sucked in from the bilge and is therefore practically the same temperature as the water. Similar to water cooling, this saves considerably in the Baltic Sea, but not so much in the tropics with a water temperature of 27° to 30°. A freezer was deliberately omitted, as the difference between 30° and -15° makes it clear that this is associated with considerable power consumption. Thicker insulation can reduce heat loss and therefore electricity consumption, but the insulation should be at least 12 cm thick, or better 20 cm thick, so that consumption is manageable. This means that a freezer represents a considerable space requirement, which is accepted and/or taken into account on very few production ships. Would we build another boat, we would specify much thicker insulation. With our set-up we calculate 40 to 60 Ah for each of the two refrigerators.

An electric autopilot is standard for long-distance sailors and under no circumstances should an undersized system be specified. It has to do its job in all weathers at all times, especially in rough weather. For a crew of two, having to steer by hand on an ocean crossing is the ultimate punishment. On many ships, including ours, a second full autopilot is carried or already installed for safety reasons. Unfortunately, the power consumption of the autopilot is considerable, especially when there is a lot of wind and waves. With the Simrad AC42 installed in conjunction with a Jefa J-DU-TS8-12 motor, the average power consumption can be between 1 A and 6 A and this must of course be multiplied by 24 hours for long distances.

For reasons of reliability and the absence of any power consumption a Monitor servo pendulum rudder wind vane control system is used on our ship for longer distances (> 4 days). The electric autopilot is then only used under engine power or in very light winds. Under these conditions, however, it consumes little power. Experience from the last 4 Atlantic and Pacific crossings has shown that the wind vane is used about 79% of the time, the autopilot 20% and the manual steering well under one percent. When anchoring and on shorter trips, the wind vane lives down below in the lazarette (evasive maneuvers, port approaches).

The water maker is also a relevant consumer. About 40 to 50 liters of water are used per day for drinking, showering/washing and cooking, which requires about 50 minutes of operation of the watermaker. It is relatively easy to choose when to run the watermaker: either at least once every

4 days so that the membrane does not get dirty, preferably at midday when the sun is at its maximum or when there is a combination of sun and wind, or when the engine is due to run anyway, such as when there is a calm or a change of anchorage. Of course, a longer engine running time in light winds is ideal. In order to almost completely avoid the use of plastic drinking water bottles, a separate 60-liter PE drinking water tank was installed, which only holds water from the water maker and has its own tap with foot pump; even in a marina, no water from pipes or hoses gets into it. This makes fantastic tea and, in conjunction with a Sodastream-like device, delicious sparkling water. This completely eliminates the need to use mineral water in plastic bottles. And the espresso tastes better too.

There are also some 230 V-based appliances that significantly increase convenience on board. These include the baking machine, the Nespresso machine, the washing machine and the electric kettle. First of all, an important preliminary remark: the 230 V on board comes from an inverter. Powerful inverters, such as the Victron Phoenix multiplus used here, consume electricity even if no 230 V consumer is connected. The Victron mentioned, for example, consumes approx. 3 A at rest. Within 24 hours that would be 72 Ah, which is of course unacceptable. For this reason, the inverter should only ever be switched on when it is actually needed and afterwards switched off. Smartphones, for example, should never be charged via the 230 V chargers, but via USB sockets that are connected directly to 12 V. If the latter option is not available, e.g. for electric toothbrushes or similar, then these should be charged when the inverter is on anyway or when the boat is running under power. An alternative is also to have a second, smaller sine-wave inverter of 300 W or 400 W which will only use som 0.4 A at rest. This is also a good solution to supply power to a StarLink modem.

Fig. 7 Enjoyment on board: A latte is quite realistic and, if the sun is shining, the tea water can also be heated electrically.

In many countries around the world, there is no bread that is compatible with German palates. In addition, the shelf life of bread is quickly exceeded on transoceanic voyages. For these reasons, an electric baking machine on board has proven its worth. It has two more advantages over the oven: You save on propane/butane, which is not always easy to obtain abroad, as the gas cylinders cannot be filled due to incompatible connections or often simply because of legal regulations. Furthermore, a baking machine heats up the space below deck considerably less than the oven on the stove. This is a relevant reason in the tropics. A typical bread baking program for 500 g of flour requires around 20 Ah.

A small Nespresso machine can significantly improve the quality of life for caffeine lovers. It requires around 1200 W, but only for a short time; 20 s for heating up and 80 s for a large cup of lungo. If the inverter is only switched on for the boiling process, this results in a consumption of around 5 Ah for 2 large cups.

Running a washing machine without shore power - is that possible? It is desirable, because experience shows that the laundry service in developing countries often leads to the loss of beloved items of clothing (the service provider often mixes the laundry from different boats in order to better utilize the machine), or to the fact that the colors develop towards a uniform grey, or that one's own skin reacts allergically to the detergent used. If you look at what a washing machine needs its consumed energy for, it quickly becomes clear that it is mainly the heating of the wash water that consumes energy. For a 60° program, this is 90%. However, as the washing performance is better with warm or hot water, an alternative method had to be found. The solution was a mixer in the washing machine inlet, which mixes water from the boat's hot water boiler with water directly from the tank to the desired temperature. This can be done manually in the form of a three-way tap or electronically controlled with an MS1002 controller. So, if a 60° washing load is required, "cold" or "30°" is set on the washing machine control panel and the hot water is simply fed in for filling in the main wash cycle. As the water supplied is warmer than the set temperature, the machine will not heat up and will only consume a small amount of electricity for the motor drive. The water in the boiler must of course be heated beforehand by combining it with the motor running time or operation of the diesel heater.

The 3 kg washing machine consumes 0.15 kWh in a cold program, which corresponds to 13 Ah from the 12 V mains plus 6 to 9 Ah for the inverter. Then there is the water consumption of 36 l in the Eco program and 50 l in the normal program. This keeps the watermaker busy for 40 to 50 minutes and requires around 30 Ah. So you have to reckon with a total of 50 Ah. Of course, it makes sense, although it is not absolutely necessary, to schedule the wash shortly after a motor phase or - if the water is calm - during motoring.

If the SOC (state of charge) of the batteries is close to 100% or it is expected that the solar panels will bring the SOC to almost 100% during the day and there are no plans to bake or make water, then an electric kettle is used to make tea. This is quicker and saves propane/butane. When choosing a kettle, make sure that it has less than 2000 W if possible. Some smaller kettles have around 1600 W. Ours has 2000 W and therefore draws 175 A. It takes 300 seconds to heat the 1.5 l teapot, so the consumption is 14 Ah.

Most of the other 230 V appliances on board do not require high power. These include chargers for the Dyson vacuum cleaner, for electric toothbrushes, for shavers and for electric battery-powered tools. What is relevant here is the inverter's own consumption and the often long charging times. With a charging time of 10 hours, for example, 30 Ah are required for the inverter alone. These devices should therefore be charged at least simultaneously or, ideally, while the engine is running. If at all possible, however, charging should be carried out directly from 12 V or via USB sockets. Most smartphones, tablets, battery-powered flashlights and GoPro cameras, for example, can be charged via USB. Car charging plugs are used for charging computers. These are now available for charging via USB-C plugs with up to 36 W. This significantly reduces losses compared to charging via 230 V and inverters.

Electricity storage

The power is stored in 6 AGM Lifeline batteries with a total capacity of 750 Ah. The 6-year-old battery bank shows almost no loss of capacity despite constant use. Three years ago, the battery bank was supplemented with a block of 6 BOS LE-300 LiFePO4 cells. These are simply connected in parallel. The mechanism of action is twofold. On the one hand, this block with its 154 Ah capacity performs a significant proportion of the partial charging and discharging processes. This reduces the lead battery aging. More important, however, is the fact that this additional battery significantly increases the average charge level of the lead battery (SOC). One of the main problems with lead-acid batteries is that the last 10% of charge is only absorbed very slowly, regardless of how good the regulator or charger is. In practice, it is almost impossible to charge a lead-acid battery to 100% using a generator or alternator on the main engine. The noise and wear and tear on the combustion engines are not in good proportion to the yield of a few percent charge. On the other hand, to maintain the capacity of a lead-acid battery and thus its service life, it is very important that it is always as fully charged as possible or at least fully charged regularly. If you are regularly moored in marinas, this is achieved by using a good charger on shore power. But many blue water sailors practically never moor in a marina and often there is no marina at all. As a result, the service battery on many long-distance sailing boats is never charged above 80% to 85%, which reduces the service life.

If the lead battery only draws a small amount of current above approx. 90% SOC, the small lithium block will still charge quickly. Once the charging process is complete (engine off), the built-in battery management system of the small lithium block then transfers its charge slowly to the lead-acid battery, thus charging it fully. Since the LE-300 has been connected, the AGM lead-acid battery has been charged to 100% much more frequently, which has certainly had a positive effect on its service life. The only downside: the small lithium battery has a different Peukert factor and charging efficiency than the lead-acid battery. As a result, the Philippi battery monitoring display is somewhat less accurate. For this reason, a Balmar SmartGauge was also installed, which indicates the state of charge of the AGMs directly.

Peculiarities

Some special features and experiences should be pointed out. First of all, there is the 60 Hz problem. In the USA and many countries influenced by the USA, electricity comes out of the socket at 60 Hz (50 Hz in Europe). This has no effect on the vast majority of appliances, only the washing machine consistently refused to work at 60 Hz. Presumably the spin speed would then be dangerously high, which is why the control electronics prevent this. Unfortunately, the frequency cannot really be changed. The operation of the washing machine in America therefore had to be based on the method described above (operation via inverter with external supply of hot water). To do this, the shore connection must be temporarily unplugged, otherwise the 60 Hz would come on board. The inverter, on the other hand, generates 50 Hz on its own.

Another surprising observation was that the respective controllers of the different energy sources influence each other. If the batteries are reasonably full and the solar system is charging at 25 A, then the voltage at the batteries is 13.4 V, for example. When the engine is then started, the ("intelligent") regulator of the alternator interprets this voltage such that the battery is practically full and it goes directly into float mode, or, since the battery voltage is already higher than the set float voltage, it shuts down the alternator completely. This has another unpleasant side effect: the rev counter, whose control voltage comes from one of the three windings of the three-phase alternator, receives no pulse, as the alternator actually receives no field voltage and then produces nothing. If a larger consumer, e.g. the watermaker, is switched on, the alternator is activated immediately and the rev counter also has something to display again.

There are similar interactions between the regulators with the other voltage sources. In some cases, the charging power of a solar bank can be increased by briefly disconnecting it from the boat electrical system and reconnecting it. The controller then starts a new charging cycle with a bulk–absorption–float and therefore outputs a significantly higher voltage for the time being.

Quintessence

With a combination of selecting the units (solar system, wind vane steering, efficient engine-charging electrics), avoiding freezer and air conditioning, and optimizing the time sequences (making water, washing machine), it is possible to enjoy a pleasant level of comfort even without a generator on board and at the same time live a certain degree of sustainability. Except in very unfavorable conditions (perhaps 3 times a year), we have not had to run the engine for charging reasons alone in the last 6 years.

A minor disadvantage is that the electrical system requires a certain amount of supervision and understanding from all members of the crew. It's not quite the case that you can say "What’s the problem, the electricity comes from the socket!"