Sizing and assessment of an off-grid PV system using a Lithium battery bank

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Abstract

In the thesis work, a validation of household consumption and load demand (size) is made via a created interactive spreadsheet further correlated with the system design tools of software PVsyst. The main objective being appropriate off-grid system design and assessment. The system is to be comprised of any number of Solar Photovoltaic panels and Lithium battery units. After validating the load demand of a common household, three simulations are made with software PVsyst, one for a daily excessive consumption, another for an optimized daily consumption and finally one for a monthly approximation consumption made by mixing the load demands for the first two simulations.

The reports for each simulation are analyzed and discussed with detail, with emphasis in parameters of losses, generation, consumption and system performance. Finally a proof-of-concept case is presented that is the system present in the sailing vessel SV Delos. Its system is comprised of (mainly) Solar generation and a large Lithium battery bank. SV Delos can house a crew of 6 and supply their energy needs with easy whilst being completely off-grid.

Keywords: Solar Photovoltaic, Off-grid, Lithium battery bank, Mobile Solar PV system, Renewable Energy

1. Introduction

The motivation behind the thesis work comes from an urgent necessity in finding alternative domestic energy supply systems that are compatible with an overarching sustainable development strategy. Whether rural or urban, stand-alone systems have their advantages and disadvantages, one could argue that both have their respective time and place for implementation. However, there are situations where a grid connection is just not feasible or even economically viable. Isolated rural spots suffer the most from lack of access to an energy supply that can satisfy the basic needs of the 21^{st} century. Furthermore, with an increasing unpredictability of weather events/political instability that displaces large populations, an increasing demand for fast deploy systems that can supply energy to medical providers and dislodged families has presented itself with urgent necessity.

That may not be the case in an urban setting, where there is vast access to the energy grid. Nonetheless the housing crisis that plagues younger generations - like my own - opens a clear pathway for smaller (yet powerful) scale systems. From a small house, up to a communal neighborhood generating its own energy grid to even mobile systems like Van conversion or Sailing Boats, the technology nowadays is capable to respond to the needs those systems imply, presenting an alternative that as of yet is a small niche but in the future has a large cap on its potential to offer alternate and independent solutions to their users. Said systems are the core of this work, where two Solar Photovoltaic (PV) + Lithium battery systems are put to the test on whether they are feasible and robust in order to serve a specific purpose that is supply energy to a household without grid support and an autonomy of five days or as in the proof-of-concept a sailing vessel. With the current technology of Lithium battery cells, PV panels and an MPPT this work will try to validate that a domestic system can be implemented and support the daily loads of a domestic household at a long term.

2. Introduction - extended

Considering the context explored throughout the thesis work, the objective is validation of feasibility of a regular domestic sized system through the use of a combination of Solar PV panels and Lithium (LFP) batteries. The system is to be configured by default on a DC mode without the use of an inverter although naturally the inclusion and small changes for different implementations needs to be a choice and not an hindrance that makes the system implementation impossible. To do that a calculation spreadsheet was made with software Microsft Excel that is capable of sizing the power loads of any domestic system and offer information about tension drops throughout different circuits of the system if the desired circuit length is introduced beforehand.

Figure 1: Excel Spreadsheet - Main loads table.

The data from this spreadsheet is then further validated by the use of the software PVsyst, where three simulations are made and its results confirming the validation of the system structure are discussed. Finally the work concludes with a proof-of-concept case, that due to the nature of its implementation and available data supplied proves to be a valuable addition in understanding the range off-grid systems have.

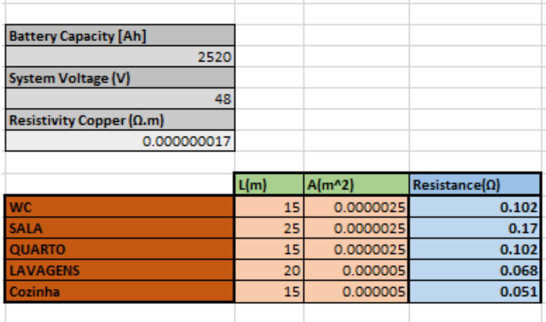
3. Methodology

The methodology behind the thesis work was divided in two fronts, one for validating Household consumption (appliance load management) through data collection and calculation for two separate days (excel interactive spreadsheet), and the other to compliment the robustness of Household consumption through the sizing of the system with the aid of the PVsyst software.

The Excel® spreadsheet was elaborated with a clear purpose of being developed into a sizing tool later on, as obvious as it is that no two systems are alike and that a strong planning phase is crucial to the development of any PV off-grid system, the need for a tool that can be adaptable to multiple parameter changes presented itself.

As the Excel spreadsheet deals mostly with loads, the parameter of Voltage Drop $[V_{Drop}]$ and its effect on the system was dealt with there. A small calculation toolbox (Figure 2) was devised where the user can input three sets of parameters in order to calculate the resistance throughout the cables/harness of the system.

First, given the power of the load (Equation 1) and the voltage of the system, we can extrapolate the current the appliance draws from it (Equation 2). Secondly, parameters such as Length (m) of the cables, the section area of the cables (m^2) and finally the resistivity of the materials of which the cables are made of (Ω.m), when combined, and these values are inserted in Equation 3 for the Calculation of Resistance, the output represents the resistance (Ω) the cables exert on any given circuit that is being calculated. With that value of resistance, the Excel spreadsheet can calculate the voltage drop.



Battery Capacity [Ah]			
2520			
System Voltage (V)			
48			
Resistivity Copper (Ω.m)			
0.000000017			
	L(m)	A(m^2)	Resistance(Ω)
WC	15	0.0000025	0.102
SALA	25	0.0000025	0.17
QUARTO	15	0.0000025	0.102
LAVAGENS	20	0.000005	0.068
Cozinha	15	0.000005	0.051

Figure 2: Excel Spreadsheet - Resistance calculation toolbox.

$$P = U * I \tag{1}$$

$$V_{Drop} = R * I \tag{2}$$

$$R = \frac{\rho \times \mathrm{L}}{A_{cs}} \tag{3}$$

Finally there is the core of the spreadsheet (Figure 1), which is a massive table where all the different circuits the user is planning on creating for their system are laid out, inside of which all the loads are specified with their respective average power consumption, description and through the aid of a visual colored coded system, their allotted usage time is laid out throughout the 24 hours of a day in 15 minute segments, that results in ninety-six 15 minute entries, for all the loads allowing the user to specify in which hour of the day they are planning on using them. Loads are specified per time-slot and when combined with the automatic calculation for hours that a load is active “TOTAL [h]” the user is presented with the column for energy consumption “Total energy [kWh]”.

The “Total energy [kWh]” by itself is a good indicator for what size a PV off-grid system should be, further on these values - the sum of them more precisely - are be similar and within a small margin of error of those that are provided by the PVsyst software. Therefore PVsyst serves as a degree of validation for the spreadsheet.

The user will also have the chance to specify passive or “stand-by” loads. For that the user should add to the “Loads (description)” column which loads they normally would leave on standby. In an off-grid system where capacity is limited, all consumption counts, and for that the user is advised to indicate which loads they normally leave on standby. This presents the user with accurate values for stand-by consumption and encourage behaviour adjustment regarding those loads([3]), ([4]).

The second part of the methodology for the thesis work was made with recourse to the system designer software PVsyst®. This software was chosen due to its ability to design an off-grid PV system that allows its user to input significant parameters deemed important for the validity of the thesis work. The software in and of itself is a rather complex tool that works significant amounts of different data in order to design/propose a viable system that fits the user's needs. To do that, a linear construction and assembly of parameters needs to be done, each step providing more information to the software.

The first step in designing a system that works with the Sun being its primary source of energy is the system's location. With the system location the software can then fetch a Meteo file from different databases (and can also convert other meterological databases to a format compatible with the software). This is important as it provides two crucial parameters which are : Horizontal Global Irradiance and Ambient temperature.

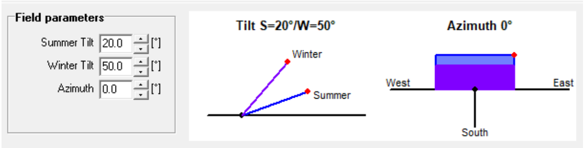

Field parameters
Summer Tilt 20.0 [°]
Winter Tilt 50.0 [°]
Azimuth 0.0 [°]

Figure 3: PVsyst software - Project design, Field parameters.

The software presents the user with a toolbox where they will define the number of loads (appliances) to be active during the day, their power rating [Watt] and finally the number of hours that the user is planning on having them active. This is the part of the software that is replicated and more scrutinized in the Excel spreadsheet. It is paramount that the information is the most similar it can be between the software PVsyst and the Excel spreadsheet in order to have a good and corroborated match in the results of the simulation. For that the user can specify which hours of the day the loads they defined will be active through the use of a visual tool similar to a clock as can be seen in Figure 4.

There was a 4.8% deviation between the two Final consumptions due to the fact that loads within the Excel environment were easier to specify than on the PVsyst software. That margin was taken into consideration and found to be within an acceptable margin of error, and that the deviation in consumption would not affect the final results the simulation would yield.

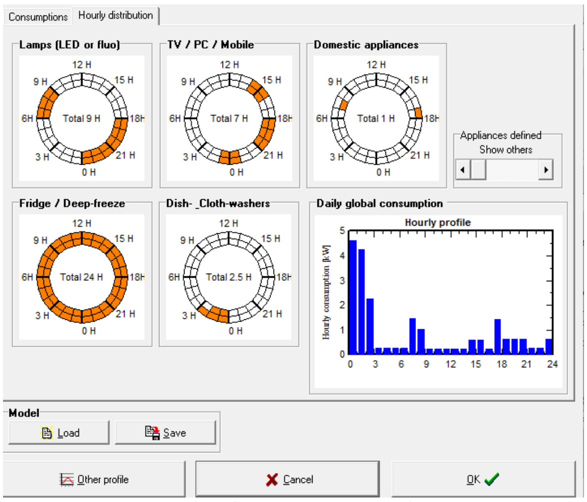
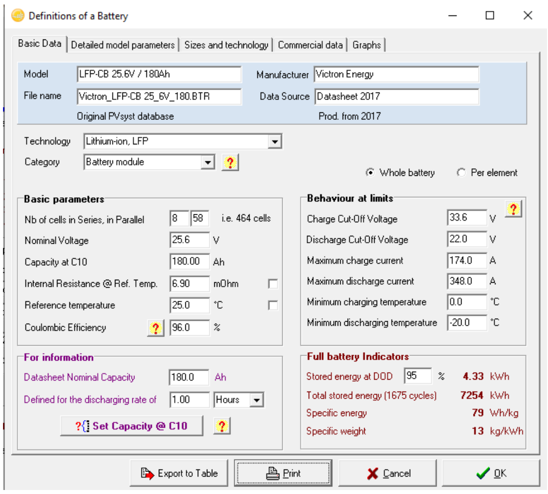


Figure 4: PVsyst software - Hourly profile distribution.

For the system itself, the PVsyst software has a highly detailed toolbox that allows the user to fine-tune most of the aspects of an off-grid PV system. First and foremost a Pre-sizing suggestion work space shows 3 major parameters: accepted LOL%, autonomy days and battery voltage. The LOL probability or Loss of Load is the probabilistic value that the user's needs that were defined in a previous step cannot be met. It is calculated as a fraction of time when the battery pack's charge [SOC] is below the threshold of minimum charge that system will define. For a Lithium battery pack the value was defined to be between 20 and 25% ([12]). The autonomy was defined to be 5 days, this value represents the number of days the system can function and supply the user's needs whilst not receiving charge from the solar panels.

Finally the user is prompted to define the battery voltage. Although the software in its manual suggests 12 to 24V for house appliances and domestic use, in the thesis work it was chosen a value of 48V due to several reasons, the first being that one of the objectives of this work is to prove an alternative to energy supply for common households, which have common appliances i.e. ones with greater power demand than 1000W such as normal washing machines microwaves and the like, and the greater the power demand is the greater the potential for V_{Drop} to occur beyond safe values for the system, hindering it by default due to poor planning. A design flaw that is easily fixed by raising the tension at which the battery pack operates. Secondly, the system having a battery bank with greater Voltage level allows the system to have a greater cable length, also preventing V_{Drop} problems due to small electrical conduit length, which increases resistance and therefore potentiates the creation of a drop of tension between battery pack and user end appliances. To conclude the pre-sizing suggestions, the software, based on the defined aforementioned parameters suggests a value for overall capacity of 2466[Ah] and PV power 5.26 [kWp]

The next step was selecting the models of Lithium batteries that would be used for the system. The model was selected given its high capacity of 180Ah and operating voltage of 25.6V. A base operating voltage of that value means that to achieve the desired 48V of system operating voltage the user would only need to put 2 modules in series and the remaining ones in parallel, thus maximizing capacity. The final number of modules was 16. The selected model was: LFP-CB 25.6V / 180Ah which has the following characteristics seen in Figure 5.



Model: LFP-CB 25.6V / 180Ah
Manufacturer: Victron Energy
File name: Victron_LFP-CB 25_6V_180.BTR
Data Source: Datasheet 2017
Original PVsyst database
Prod. from 2017
Technology: Lithium-ion, LFP
Category: Battery module
● Whole battery ○ Per element

Basic parameters
Nb of cells in Series, in Parallel: 8 58 i.e. 464 cells
Nominal Voltage: 25.6 V
Capacity at C10: 180.00 Ah
Internal Resistance @ Ref. Temp.: 6.90 mOhm ☐
Reference temperature: 25.0 °C ☐
Coulombic Efficiency: 96.0 %

Behaviour at limits
Charge Cut-Off Voltage: 33.6 V
Discharge Cut-Off Voltage: 22.0 V
Maximum charge current: 174.0 A
Maximum discharge current: 348.0 A
Minimum charging temperature: 0.0 °C
Minimum discharging temperature: -20.0 °C

For information
Datasheet Nominal Capacity: 180.0 Ah
Defined for the discharging rate of: 1.00 Hours

Full battery Indicators
Stored energy at DOD 95 %: 4.33 kWh
Total stored energy (1675 cycles): 7254 kWh
Specific energy: 79 Wh/kg
Specific weight: 13 kg/kWh

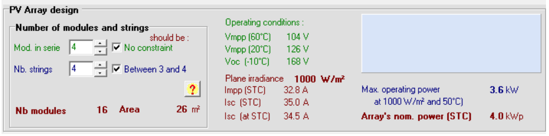
Figure 5: PVsyst software - Storage definitions.

For the PV modules, a generic 250 Wp 25V (60 cells) model was selected. Instead of following the suggestion for planned power of 5.2 kWp, in this step a limitation in occupied area was the chosen approach. Note that with current and in development technology, the roof is not the only alternative for panel placement, solutions with vertical adjustable panels already exist and maximize the vertical facade of a building ([6]), as well as PV tiles.

With the area constraint, the software suggests 4 modules in series with a total of 4 strings, a total of 16 panels with an occupational area of 26m^2 culminating on an array with 4.0kWp nominal power @STC. The panel's characteristics can be analyzed below on Figure 6.

4. Results & discussion

In the results section of the thesis work, three simulations performed on the software PVsyst were scrutinized and discussed. These simulations have the same parameters that were explained in the Methodology chapter and have the same input data regarding loads that was present in the excel spreadsheet. The three simulations are the ones for the "Worst case consumption", the "optimized consumption" and finally a third one for a "monthly approximation" of load demand. The latter was made due to the fact that the software can't accurately process a 7-day week cycle where the loads vary from day to day, namely due to the difference caused by the usage of the appliances in the "Washing Room "circuit. The approximation made was that for any given 7 day week cycle, the appliances would operate no more and no less than 3 days per week, and this approximation was made as an average approach based on personal experience.



should be :
Mod. in serie: 4 ☑ No constraint
Nb. strings: 4 ☑ Between 3 and 4
Nb modules 16 Area 26 m²
Vmpp (60°C) 104 V
Vmpp (20°C) 126 V
Voc (-10°C) 168 V
Plane irradiance 1000 W/m²
Impp (STC) 32.8 A
Isc (STC) 35.0 A
Isc (at STC) 34.5 A
Max. operating power at 1000 W/m² and 50°C) 3.6 kW
Array's nom. power (STC) 4.0 kWp

Figure 6: PVsyst software - PV Array design.

The transposition model used by the software for its simulation is the Perez model for radiation on slopped/tilted surfaces and not for example the Hay, HDKR or Liu Jordan ([7]). It is called transposition model because it is the calculation of incident irradiance based off of horizontal irradiance data. This model proves to more useful as it takes hourly data sequences into account, however this model requires well measured horizontal data ([8]). One side note of this model is that, depending on plane orientation, its values for yearly averages of irradiance are slightly higher than the one's from the Hay model, but not greater than 2% ([10]).

Moving onward to the characteristics of the chosen panels, the simulation was done using a generic sample Poly 250Wp with N_s=60 cells. The number of suggested panels for the "worst case" system was 20, with the following disposition of 4 strings in parallel with 5 modules in series. The unit nominal power of each panel is 250 Wp and for the total array described the global power is 5000Wp (4474 Wp at operating conditions – 50ºC).

The array's operating characteristics (at 50ºC) are U_{MP} 136V, I_{MP} 33A. Note that for a larger system like this a common solar MPPT charger with 100V 50A limits is not advisable given that the output voltage is greater than the threshold, that however is not the case for the other simulations where a common solar mppt charger (100v – 50A) more than capable of handling the respective arrays.

One direct consequence of having more panels suggested for the "worst-case simulation" and the "monthly approximation simulation" was the increase in panel area. For this factor the software allows to hard-cap the value, and the limits used were 30m^2 and 20m^2 for the worst case/ monthly approximation simulations and optimized consumption respectively. The module area was 32.5m^2 and 19.5m^2 and the effective cell area for the 20 and 12 panels was 29.2m^2 and 17.5m^2. These were the values for the simulation to compute efficiency as per Equation 4.

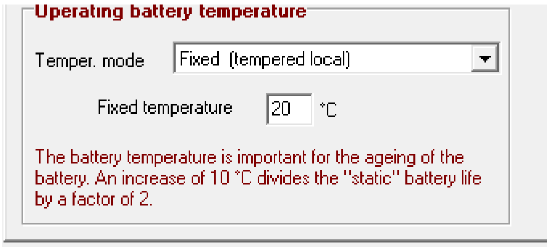
$$\eta = \frac{\mathrm{P}_{max}}{A \times G} \tag{4}$$

The next part in the analysis of the simulation was the Battery Pack Characteristics. Here there is also a difference between the “worst-case” simulation and the optimized consumption/monthly approximation simulations. However instead of being caused by lack of supplied power it is caused by lack of capacity as the system requires a bulkier battery pack in order to accommodate the heavier consumption of the “worst-case” simulation. If the system was undersized or sized in the same manner as the other two simulations, an autonomy of 5 days would not be achievable. Since that parameter takes precedence, the software increased the battery pack size.

The model selected was Victron Energy’s LiFePO4 battery 25.6V 180Ah battery module. The technology of Lithium Iron Phosphate was selected due to various reasons, namely: high energy, power density, low discharge rate and overall usage of available capacity. These LiFePo4 batteries are able to be charged at a more efficient rate than their competitors and the tendency is to increase that efficiency as new methods are developed regarding charging of these types of batteries ([11]).

Regarding the lifespan of these batteries , there is some divergence on the results, while most paper’s claim around 10 years, the fact is that it has not passed that amount of time since the inception of this technology so that value is an estimate derived of cycle stress and durability tests ([12]). And when researching literature for this work, the emphasis of research appears to be on storage conditions, as those have the most effect on the quality and durability of these batteries ([5]). In the simulation a mean value of 20ºC was used to compute ageing. The software shares the following estimate based on a 10ºC increment in temperature and its effect on “static” battery life.

The Controller selected was a Universal controller with a DC-DC converter. The goal of the system is that it runs on its entirety with DC current however there is always the possibility placing a capable inverter in this phase, or some punctual inverters for loads that must run on AC. The values for appliances that were computed for both the simulations and excel worksheet were values commonly found on those respective versions of DC run appliances. The Maxi and EURO efficiencies for the converter were 97% and 95% respectively, and as the controller is common to all three simulations there was no difference on those values.



Temper. mode: Fixed (tempered local)

Fixed temperature: 20 °C

The battery temperature is important for the ageing of the battery. An increase of 10 °C divides the "static" battery life by a factor of 2.

Figure 7: PVsyst software - Operating Battery temperature

The next results to be analyzed were the Normalized Energy Productions of the system and the comparison between Performance Ratio and Solar Fraction. For all three simulations PR and SF were compared with aind to graphics created by software PVsyst as can be seen in Figure 8.

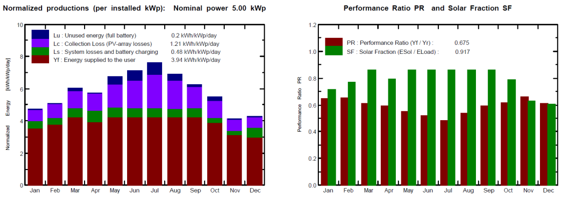


Figure 8: PVsyst software - Normal productions and Performance Ratio vs Solar Fraction the ”worst consumption simulation”.

One of the best features the PVsyst software has is the construction of a Losses diagram where the user has the chance to visually see and understand where their system has the most losses. an example of the diagram can be found on Figure 9.

As was expected, since the simulation runs bases on the same meteorological database, some loss parameters pertaining to Irradiance, irradiation and temperature and its effect on the losses are the same between simulations.

The conclusion to the chapter and to what possibly is one of the key indicators of the viability and effectiveness of a system, the loss parameter Missing Energy was addressed. Missing energy, as is, is not a deterrent to a good functioning system, PVsyst indicates a system may be perfectly sized but still Missing energy can occur. It has a direct connection with user loads and availability of stored or direct power. An important note is that the values present in the losses diagrams are for the whole year and with a 4 day autonomy. Therefore theoretically, a user may not even find a problem with missing energy whilst using the system. A Value inferior to less than -5% seems acceptable when putting those factors into perspective,

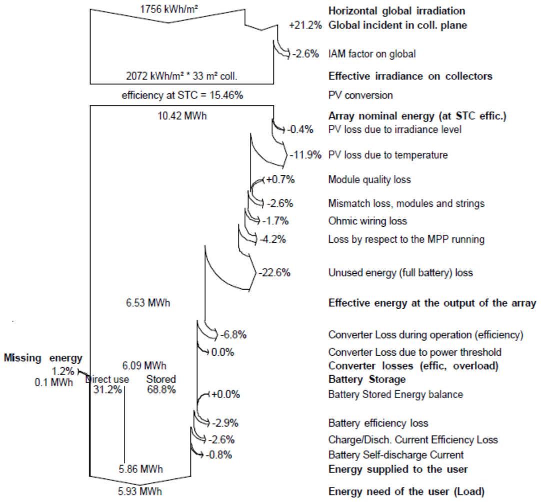


Figure 9: PVsyst software - Loss Diagram over the whole year for the ”monthly approximation consumption simulation”.

and with fine-tuning load usage that loss parameter can even be thoroughly mitigated. In all the three simulations the worst value for Missing energy was - as expected - the “worst case simulation” where it assumed a value of -8.3% which is almost 7 times the one for the “monthly approximation simulation”.

When designing a system such as the one proposed on this work it is only natural to run into possible constraints and bottlenecks when considering their implementation. Aside from power constrains that were addressed, the most notable and with higher probability of occurrence is insufficient available area. In the simulations performed the implementation of the panels is to be made on a roof's tilted surface, and those panels would be subject to a seasonal tilt adjustment in order to achieve the better performance possible. For the three simulations made, the necessary available area was 32.5m^2 for the simulations that had 20 panels and 19.5m^2 for the simulation that had 12 panels. Note that for roof area we are only considering the part that has good southern exposure i.e. half of the normal total roof area. For a normal Portuguese home, the area values suggested are a tight fit. That however might not be the case for other homes, at least not in its entirety. For houses where there is a lack of available roof area other solutions must be devised in other to implement a system capable of supplying the necessary energy to fulfill the user's needs. One of the most promising solutions to address that problem is the implementation of Solar tiles in a BIPV logic whether it being solar roof tiles or even solar facades. Solar roof tiles have the advantage of being able to be deployed on roofs with less loss space in-between cells or even in a building facade ([2]).

These solar roof tiles incorporate in their design a PCM that allows for a boosted electrical output and have an economical payback time of roughly 6 years. ,Improving performance of solar roof tiles by incorporating phase change material ([1]).

The other implementation tactic is the development of multi purposed solar facades, that in addition to providing an electrical contribution to the building where they are deployed, they can also deal with shading, ventilation and even thermal insulation ([9]).

For the proof of concept of the thesis work – and what inspired me to address this topic – a sailing vessel powered mostly by renewable sources was chosen. That vessel is SV Delos, star of a YouTube Adventure series where its crew travels around the world to the most remote locations. The focus will be its power generation (solar) and how it is achieved, through a breakdown of its system components and notable loads.

Whilst making this work, I was fortunate enough to contact the crew and get extra data concerning power generation and consumption aside from the one made available on their website. SV delos is a French built 53ft Amel Super Maramu that has a capacity for a 6-person crew. As of making this work SV Delos is equipped with: eight 100Ah DragonFly Energy batteries (in a 400Ah 24V configuration), two 330W Canadian Solar rigid panels on the back of the boat, six flexible panels on the front two 170W and another four 110W which totals to 1440W of nominal solar power (Figure 10, which for a boat – or any system for that matter – is a considerable amount.

Figure 10: SV Delos - Center mounted flexible 2 170W and 4 110 W panels.

SV Delos underwent a battery pack change from Lead acid to Lithium, and in doing so significantly increased its solar energy production. This was due to the much greater charging efficiency of the Lithium battery cells (30 to 40% greater than Lead-Acid). Before the change, the solar array was producing roughly 3-3.5 kWh daily and after those values increased to 4kWh which in the words of its Captain was almost like adding a new solar panel and well worth the change.

For a closer look and to better understand the dynamics of power generation and consumption Capt. Brian Trautman was kind enough to supply data directly from Victron's VE. Direct Smart phone application. Furthermore the time frame of the supplied data presents the opportunity to make an important analysis regarding the scope of this work, because there is data from when the vessel was connected to dock power and data from when the vessel was travelling high seas. In both Figure 11 and Figure 12 is the data from the solar chargers, the first from the rigid panels and the second from the flexible ones. Up until the 27th of May SV Delos was connected to dock power in Mexico, then the vessel traveled in high seas to Mexico until arriving there on June 5th. With this data the behavior of the chargers can be compared in a docked situation vs off-grid whilst traveling.

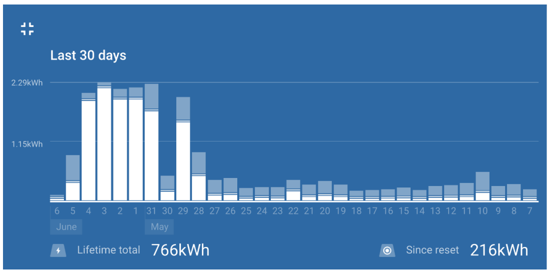


Figure 11: SV Delos - Data from the Victron Solar charger - Rigid panels 2 x 330W.

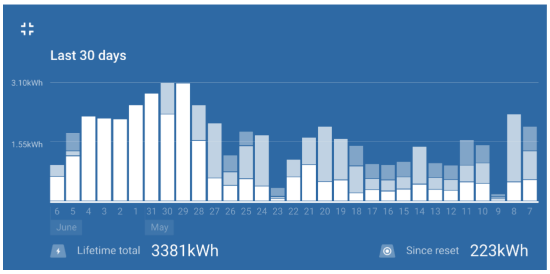
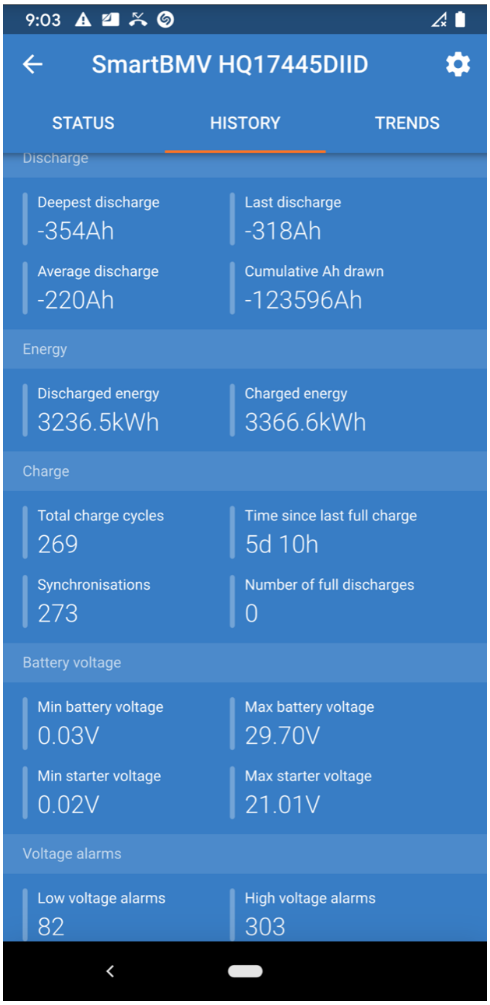


Figure 12: SV Delos - Data from the Victron Solar charger - Flexible panels 2 X 170W and 4 X 110 W.

Concerning capacity and consumption, SV Delos' captain also supplied data extracted from the Victron Energy Smart Battery Monitor BMV-712 via the smartphone application. The battery monitor connects via Bluetooth to whichever device the user chooses. In the screenshot from the application (Figure 13) the data regarding consumption (discharge) is present. As was previously mention the overall Lithium battery bank capacity of the vessel is 400Ah. The information in the screenshot shows that the average discharge is 220Ah which is around 55% of the overall capacity. This means that this system, for the loads the crew subjects the system to, is robust. Then considering the deepest discharge data which reveals that the most strained discharge of the system was 354Ah – 88% of overall capacity – shows that in addition to being a robust system, it is also a well sized system that allows considerable margin to the crew to add more demand on the batteries beyond their average use.



Discharge

Deepest discharge -354Ah

Last discharge -318Ah

Average discharge -220Ah

Cumulative Ah drawn -123596Ah

Energy

Discharged energy 3236.5kWh

Charged energy 3366.6kWh

Charge

Total charge cycles 269

Time since last full charge 5d 10h

Synchronisations 273

Number of full discharges 0

Battery voltage

Min battery voltage 0.03V

Max battery voltage 29.70V

Min starter voltage 0.02V

Max starter voltage 21.01V

Voltage alarms

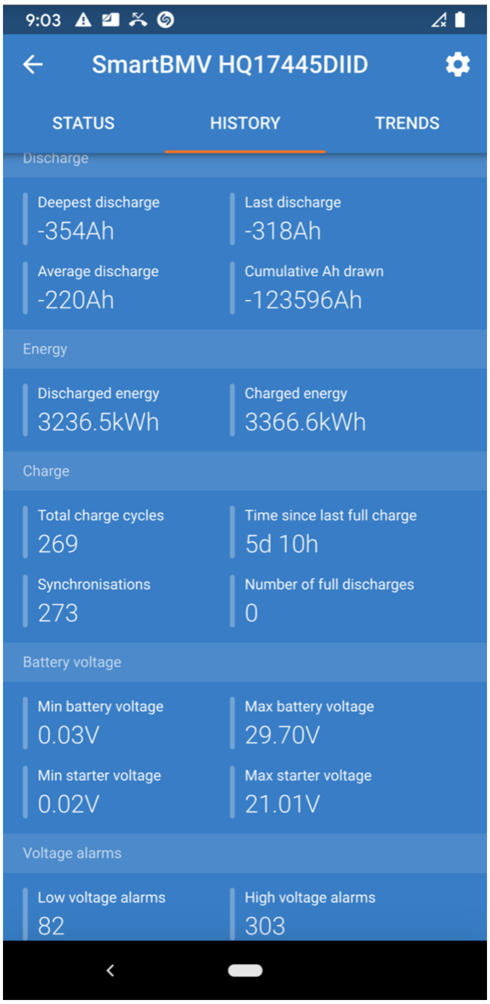
Low voltage alarms 82

High voltage alarms 303

Figure 13: SV Delos - Data from the VictronConnect smartphone application - History.

The second stage in Figure 14 shows a photograph like state of the battery at 9 A.M. (before the majority of solar energy charging occurs) and it shows the SOC at 36% and the battery pack voltage at 25.83V. At that precise moment, there were 31.4A being drawn from the batteries and a consumption of 811W of power. Finally since the last charge the system had discharged 259.4Ah of capacity, approximately 64.85% of overall capacity.

In conclusion SV Delos in my opinion is the perfect vessel for a proof of concept such as this. It is well sized and has a heavier load demand than usual for vessels of its class, the multitude of energy inputs and redundancy the system has offer greater security for its crew in what are more perilous and straining conditions than would be expected for systems such as these. It also provides



Discharge

Deepest discharge
-354Ah

Last discharge
-318Ah

Average discharge
-220Ah

Cumulative Ah drawn
-123596Ah

Energy

Discharged energy
3236.5kWh

Charged energy
3366.6kWh

Charge

Total charge cycles
269

Time since last full charge
5d 10h

Synchronisations
273

Number of full discharges
0

Battery voltage

Min battery voltage
0.03V

Max battery voltage
29.70V

Min starter voltage
0.02V

Max starter voltage
21.01V

Voltage alarms

Low voltage alarms
82

High voltage alarms
303

Figure 14: SV Delos - Data from the VictronConnect smartphone application - Status.

manufactures of products such as batteries, solar panels and controllers valuable data for what kind of stress - whether high heat in the tropics where SV Delos usually sails, or the highly saline environment of a sailing vessel - their products can withstand. The ease of access to energy related data the Victron Energy products provide also made this proof of concept that more reliable in what concerns analyzing the intricacies of how the system performs.

5. Conclusions

The implementation of a system designed to work independently from the power grid inherently places itself in the minority of electrical domestic systems. Due to the sheer nature of what off-grid means, a system designed to work solely by itself subjects the user to different types of possible hindrances, but it also provides advantages. As with any alternative to the norm, there must be a purpose for its existence, whether it being providing a solution where there is an impracticability to implement the norm, or providing different advantages that the norm simply by design can not offer. Therefore, to the perspective of the user, each case will have its pros and cons. In this case the norm as was mentioned is having a grid connected system, and the alternative – among many as they include any power delivery solution other than solely grid connected – is any other devisable power delivery system. In the case of the thesis work the alternative is a completely off-grid power delivery system, but there are also PV grid connected systems, localized microgrids and so on. The core advantage this work focuses on for Off-Grid PV powered systems with Lithium battery banks is autonomy. Whether it being a system deployment in an area where power grids are not available, emergency deployment situations or the ability to roam and travel with the normal luxuries of a 21st century home by land or by sea, this work proves the viability of that choice. The main disadvantage will always be connected to available area, but this work shows that with normal roof area in an average sized home, this systems can be deployed.

When considering future work, the direction where there seems to be a void in literature is the topic of mobile off-grid homes. The Proof-of-Concept of this work validates the feasibility of such systems and how they can thrive in a multitude of conditions. Therefore the logical step is to find the limit of those conditions by designing - and optimising - new systems based on real data from practical cases all around the world. Possibly cases where the system is already being pushed to the limits with fewer solar exposure or even harsher conditions such as arctic travel.

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