SAVONIA

THESIS - **MASTER'S DEGREE PROGRAMME**
TECHNOLOGY, COMMUNICATION AND TRANSPORT

PV-SYSTEM AS A PRIMARY ENERGY SOURCE FOR E-REV

Defining and modification of PV-system

Picture by Marko Niskala 2022

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THESIS
Abstract

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Abstract

This thesis started from an idea about modification and creating a working electricity production system to primarily produce electricity for Extended Range Electric Vehicle, E-REV / Electric Vehicle, EV.

The commissioner of the thesis was a household in Jyväskylä with an operational 780 Wp PV-system with LiFePo4 batteries. The idea of the topic emerged after purchasing E-REV and the need to get the most benefit from the commissioner’s own electricity production. However, the garage construction project slightly changed the approach regarding the solar electricity system change, which also considered the electricity distribution of both in the garage and in the house.

In this work the calculation for defining the size of the system was based on PV-system production data logged from the 780 Wp system within the years and the data related to E-REV consumption, which was logged during numerous drives by pairing a phone with a mobile application to the car.

When choosing solar panels, attention was paid to the physical size of the panel field, because at the same time as the study project, a garage construction project was underway, to which these panels were essentially connected.

In the device selection, inverters from two manufacturers were considered, and the selection criteria were based on the battery voltage and secondary voltage distribution configuration design within the project and price. Since it was a modification and expansion project of an existing system, other equipment choices considered connecting the existing battery to a larger system.

In the design of the new system also the fact that it is necessary to monitor the system's output and store data about it was considered, so a relatively large amount of time was used for creating a python-based script / program for electricity production and load monitoring system.

As a result, the electricity production did not quite meet the calculation, because during the project the solar panels turned out to be faulty. Based on the production data for 2022, an average of 190.15 kWh/month of electricity was produced from March to the end of August. This meant that the calculated yield was sufficient for 73.5% of the calculated amount of electricity and the daily driving distance was 35 km instead of the 48 km determined in the calculation.

Keywords
Photovoltaics, E-REV, LiFePo4, BMS, Efficiency, PV-system modification, Solar Battery Management System

CONTENTS

LIST OF USED ABBREVIATIONS AND ATTRIBUTES

BEV	Battery Electric Vehicle
BMS	Battery Management System
CAGR	Compound Annual Growth Rate
cron	a Unix, Solaris, Linux utility that allows tasks to be automatically run in the background at regular intervals by the cron daemon
csv file	A text file where the values are separated by a comma
DC/AC Inverter	A device converting Direct Current to Alternative Current
DSSR20	Voltage converter and control component in Solar Battery Management System
Efficiency	Amount of useful energy output relative to the input. Output divided by input
E-REV	Extended Range Electric Vehicle
EV	Electric Vehicle
HEV	Hybrid Electric Vehicle
ICE	Integrated Combustion Engine
km/kWh	kilometers per kilowatt-hour
kW	kilowatt
kWh	kilowatt-hour
kWh/km	kilowatt-hour per kilometer
LiFePo4	Molecular formula for Lithium Iron Phosphate battery
MYxxxx	Manufacturing Year, for example *MY2013*
NiCD	Molecular formula for Nickel Cadmium battery
NiMH	Molecular formula for Nickel Metal Hydride battery
Off-Grid	Stand-alone electricity production system
On-Grid	Grid-connected electricity production system
PHEV	Plug-in Hybrid Electric Vehicle
P_{in}	Input power
P_{out}	Output power
Python	Programming Language
PV-System	Photovoltaic System
Raspberry pi (RPi)	mall Single-Board computer (SBC)
RRD	Round Robin Database
RRDtool	A tool for configurating and operating Round Robin Database
SBMS	Solar Battery Management System
SBMS0	Third generation Solar Battery Management System by (Electrodacus, 2014)
SBMS4080	First generation Solar Battery Management System by (Electrodacus, 2014)
SOC	State of Charge (Determines the charging state of a battery)
STC	Standard Test Conditions
UART	Computer hardware: Universal Asynchronous Receiver-Transmitter
USB	Industry standard: Universal Serial Bus
W/m^2	Watts per square meter

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1 INTRODUCTION

The purpose of this work was to investigate alternatives for how it would be profitable to modify an existing photovoltaic system with energy storage so that it would produce electricity primarily for the Extended Range Electric Vehicle, *E-REV*. The basis of the work was to investigate, calculate, determine, select, purchase and install suitable components to modify current PV system. The idea was to get the most amount of the electricity from the sun so that diurnal travelling to workplace and back to home would be covered by own produced electricity.

Solar production data gathered from the old solar electricity system was a base for determining and selecting the size of the system, as well as some data gathered from the *E-REV* itself. Therefore, there was a possibility to evaluate the potential of solar energy source in specific location with certain number of panels by mirroring it to *E-REV* consumption.

2 LITERATURE REVIEW

2.1 Electric vehicles history

Regarding Department of Energy, The History of the Electric Car published in 2014 (Energy, 2014), tell that the very first commercial electric vehicle invented is hard to pinpoint in where it was invented. They say it was a series of breakthroughs, which led to the first electric vehicle on the road. In the publication is told that around 1830 – 1840 innovators in Hungary, Netherlands and United States started to play with a though of battery-powered vehicle and created some of the first ones of the small-scale electric cars. However, around same time period, there was a British invertor named Robert Anderson who developed the first crude electric carriage. After this time, mankind had to wait until the second half of the 19th century before some of the practical electric cars were invented by French and English inventors.

2.1.1 Electric vehicle history in the U.S.

In the U.S, there was a man named William Morrison in Des Moines, Iowa who made the first successful electric car, and which helped spark interest in electric vehicles in United States. After this within a couple of years different manufacturers cars began to appear around the States (Energy, 2014).

Even though electric cars have started to become common in Europe, at least according to the thesis author’s view, only in the last ten years or so, it is admittedly confusing to realize that the rise and fall of electric cars has been much further back in history than I thought.

At the time when electric cars started gaining publicity, vehicles that use a form of energy well known to the world today, gasoline-powered cars, also started to appear on the market. It was the Ford Model T, which affected the electric cars negatively, since gasoline-powered Model T cost approx. 1/3 of the price of the electric Roadster. In addition to a significantly cheaper price than electric cars, the invention of the electric start also turned more eyes in the direction of combustion engine cars. By 1920, the road networks also started to be at a better level in the United States, which also drove the popularity of the gasoline car up more, and since the general trend at that time was "go out and explore", electric cars, due to their small range, were unable to respond to that cry. After all, by 1935 electric cars had practically disappeared from the US market.

2.1.2 The new comings of electric vehicles

Within the history, there are a few of starts and stops related to electric vehicle industry, but I think we can only talk about the actual new arrival of electric cars when we talk about the 21st century. The Toyota Prius was released globally in 2000, the luxury electric sports car-focused Tesla as a company and car manufacturer began to rise from 2006 (Energy, 2014). Nowadays many countries are pushing towards car electrification and new electric vehicles are being sold more than ever, globally. In the USA, sales of electric cars have grown explosively between 2011 and 2015. For example, the number of vehicles sold in 2015 is more than 12 times higher than in 2011. This change can be seen in Table 1 (Elements, 2022). Abbreviation *CAGR* stands for Compound Annual Growth Rate.

Table 1. EV Sales 2011-2015 (Elements, 2022)

Year	Total EV Sales	CAGR
2011	55,414	-
2012	132,013	138.20%
2013	220,343	66.90%
2014	361,157	63.90%
2015	679,235	88.00%
Total sales / Avg growth	**1,448,162**	**89.30%**

Table 2. shows information on the sales of electric cars by country in 2021. There is also presented a percentage value of how much the number of these vehicle types has been in the total number of cars sold in the country (Elements, 2022).

Table 2. EV sales by country in 2021 (Elements, 2022)

Country	2021 EV Sales	% of Total
China	3,519,054	51.70%
U.S.	631,152	9.30%
Germany	695,657	10.20%
France	322,043	4.70%
UK	326,990	4.80%
Norway	153,699	2.30%
Italy	141,615	2.10%
Sweden	138,771	2.00%
South Korea	119,402	1.80%
Netherlands	97,282	1.40%
Rest of Europe	469,930	6.90%
Rest of the World	313,129	4.60%
Total	**6,809,322**	**100.00%**

2.2 The different types of electric vehicles

There are many different types of vehicles that use electricity in their powertrain in some way. This paragraph briefly presents the different types of electric cars such as Electric vehicle, Hybrid Electric Vehicle, Plugin Hybrid Electric Vehicle and Extended Range Electric Vehicle.

2.2.1 Electric Vehicle, EV

The EV's does not have an Internal Combustion Engines, *ICE*'s. These vehicles run on electricity and their batteries can be charged by using public charging stations, home charging stations which has installed as fixed installation and temporarily from wall socket with vehicle compatible charging cord. In some context these vehicles are called Battery Electric Vehicles, *BEV*s.

2.2.2 Hybrid Electric Vehicle, HEV

Hybrid Electric Vehicles, *HEV*s use both electricity in the battery and Integrated Combustion Engine, *ICE* to move a car. The battery is charged via regenerative breaking (Lee, 2022). HEV's cannot be charged other way. A common configuration of *HEV* is that there are *ICE*, battery, an electric motor and generator (James Larminie, 2012).

2.2.3 Plug-in Hybrid Electric Vehicle, PHEV

Plug-in Hybrid Electric Vehicle, *PHEV* is like an upgraded version from *HEV*. It has an internal combustion engine and a larger battery than *HEV*s. Like *HEV*s the *PHEV*s use regenerative breaking to transform kinetic energy into electricity. In addition, the Plug-in Hybrid Electric Vehicle can be charged from electricity network like EV's. By using electricity side by side, it allows you to cut down your gas usage up to 60 % (Lee, 2022).

2.2.4 Extended Range Electric Vehicle, E-REV

An Extended Range Electric Vehicle, *E-REV* is also Plug-in Electric Vehicle since it has *ICE,* battery and other component as in *PHEV*. The difference comparing this to *PHEV* is, that primarily it uses electricity for moving the vehicle and there is not necessarily direct drivetrain from *ICE* to wheels. *Towards Sustainable Road Transport* publication defines the E-REV as follows: E-REV is a vehicle with all the motive power provided be an electric motor, but it has a small Integrated Combustion Engine, *ICE* which generate additional electric power when batteries of the vehicle are empty (Ronald M. Dell, 2014).

E-REV's combines the advantages of *EV*s and *HEV*s (Mettlach, 2009). It acts like an electric by allowing to drive, depending on the car, 25 – 100 km by using electricity. In addition to electricity, it is possible to drive longer distances without worrying about the existing charging network by using fuel in the tank.

2.3 Photovoltaic systems

The photovoltaic systems and panels have been among us over a decade, but in a perspective of commercial use the systems have become more common approx. in the last fifty years. A solar panel usually consists of several solar cells connected to a fixed frame structure. Solar cell itself is relatively simple photoelectric device which convert solar radiation into a more usable form, into electricity. The history of solar cells goes back as far as the 19th century, when young physicist *Edmond Becquerel* discovered photovoltaics while working in his father's laboratory by immersing two different brass plates in a liquid. This experiment was shown that a continuous current was produced when those plates were illuminated with sunlight (Lynn, 2010). Around 1870s Willought Smith, W. G. Adams, and R. E. Day discovered the effect as well, but then it was discovered in selenium (Lewis Fraas, 2010).

Also, it is told that *Heinrich Hertz* discovered the effect in his studies with resonator. He discovered the production and reception of electromagnetic waves in 1887, which was later called photoelectric effect (Buchwald, 1994). Hertz's discovery couldn't scientifically be explained at the time. Quantum theory is involved in explaining this phenomenon, and *Albert Einstein* explained the phenomenon in 1905 from which he won the Nobel Prize (Lewis Fraas, 2010).

The photovoltaic system complex includes relatively much more equipment base than the panels themselves. Depending on the intended use, the system may include voltage converters, inverters, batteries and several different protection devices.

2.3.1 On-Grid system

On-Grid system is connected aside with national electric grid. In addition to the panels, this system usually consists of a grid inverter and protective devices according to regulations. Alternatively, this can also consist of microinverters and a separate grid connecting device, which handles the disconnection of the system from the national grid in accordance with regulations, for example in the event of a failure. This system is dependent on the national power grid, which means that if the distribution of the national power grid is interrupted, the solar electricity system will not produce electricity either. When considering a system for yourself in Finland, the easiest way is to get the system directly installed. Having said that, it is easiest to get the system as a complete package, because the installation and connections must be done by a contractor/person with the appropriate expertise and above all permits to perform the installation and commissioning inspections. The qualifications required of electrical installers are defined in the Electrical Safety law 1135/2016 (Työ-ja_elinkeinoministeriö, 2016) and standards must be obeyed in installations.

If, on the other hand, you want to choose the equipment for yourself, you should keep in mind the German requirements document *VDE-AR-N-4105:2018* and the standard *SFS-EN 50549-1:2019* when purchasing an inverter and protective equipment. Distribution network companies accept the VDE-AR-N-4105:2018 and SFS-EN 50549-1 standards, which define the protection levels of equipment and how they need to act e.g., in an event of national electricity grid shortage.
In other words, when the device is proven to be in accordance with the standards mentioned above, the solar power system can be connected to the national electricity grid in Finland.
It should also be remembered that it is subject to a permit to install electrical equipment with a nominal voltage exceeding 50 Vac or 120 Vdc, which is the limit between extra-low voltage and low voltage according to *standard Safety at electrical work SFS 6000-2* (Standardoimisliitto, 2015).

Related to the above, even if you intend to install the solar power system yourself, certain installation procedures must be carried out by a contractor who has the appropriate permits to carry out the installation work. These regulations are determined based on the standard SFS 6000-1:2022 (Standardoimisliitto, 2022) .

The contractors with the relevant permits are listed in the register managed by *Tukes* in Finland. In Figure 1 in the next page is presented a simplified principle of *On-Grid* system (Alternative Energy, 2013):

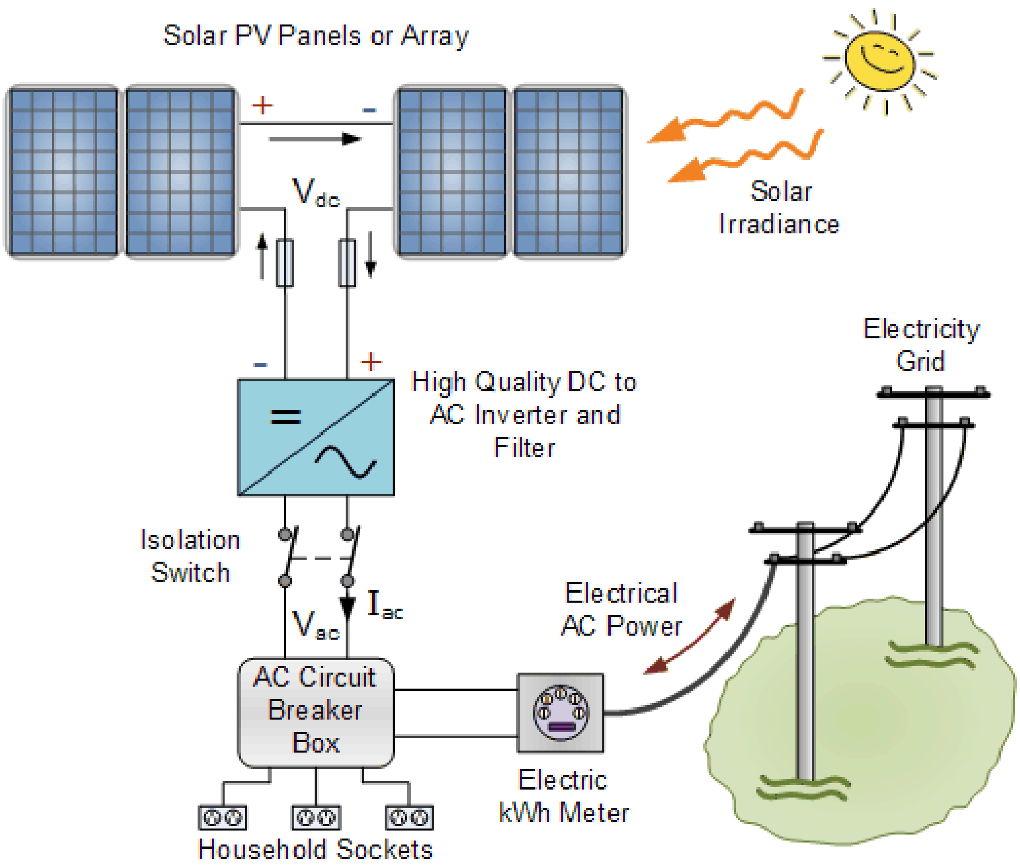


Figure 1. On-Grid PV-system (Alternative Energy, 2013)

2.3.2 Off-Grid systems (Stand Alone PV-Systems)

Off-Grid systems differs from On-Grid systems, that there is energy storage included. Also, the systems with energy storage are often installed in properties that are not permanently occupied, for example vacation homes. Alternatively, the system is installed in a permanently inhabited property, which is located beyond the reach of the national electricity network. In addition, the system can include, for example, an aggregate instead of an energy storage, or which is installed alongside an energy storage.

The small Off-Grid system usually consist solar panels, charging controller and batteries with suitable protection devices. The system may be designed the way that all electricity consumers operate on DC voltage (12 or 24 Vdc) only. Slightly larger systems may include an DC-to-AC inverters and a larger battery.

Regarding the installation, the same regulations apply to both Off-Grid and On-Grid installations, i.e. an installer with appropriate permits is required for certain electrical installations. In Figure 2 is presented a simplified *Off-Grid* system with *DC/AC inverter* (Alternative Energy, 2013):

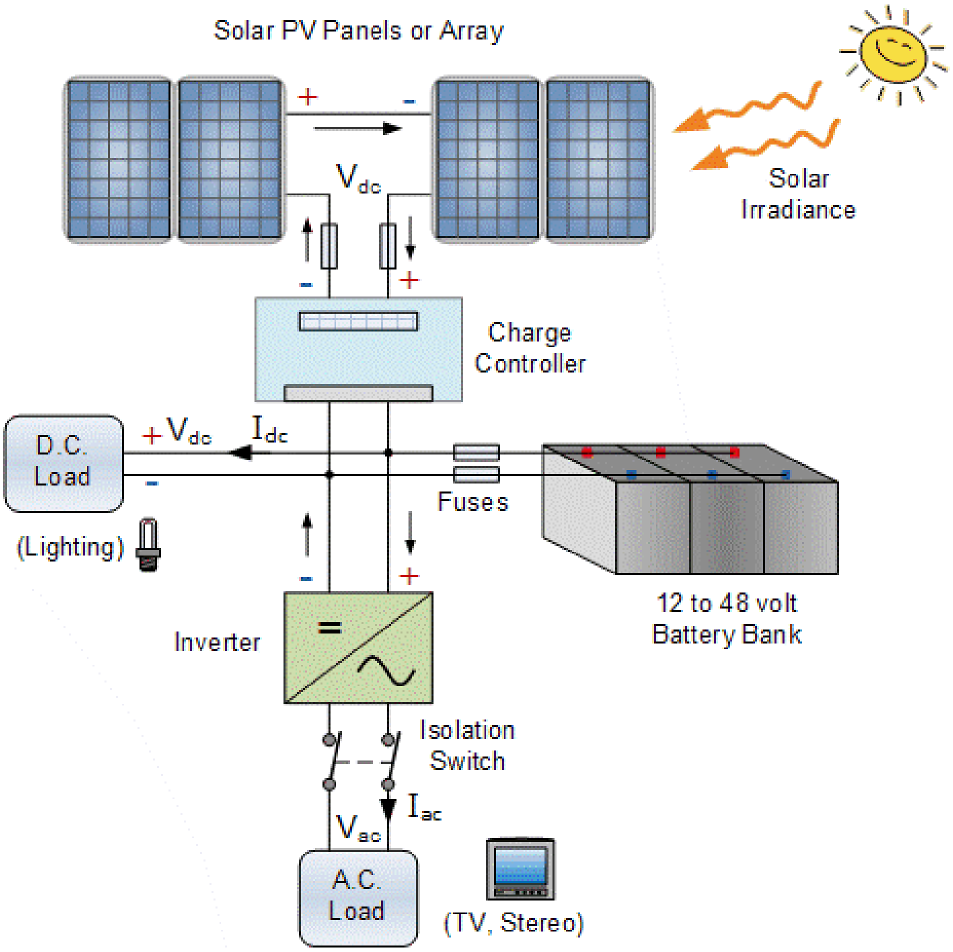


Figure 2. Off-Grid PV-system (Alternative Energy, 2013)

2.3.3 Energy storages

As you may know a common challenge in distributed electricity production is the fact that there is no constant energy flow available all the time. A cloudy summer day does not bring as much solar radiation as sunny day. So, a proper energy storage can extend the system's daily operating time if it is carefully designed from the very beginning.

Energy storage for ordinary consumers may not have developed at the same pace as demand would require. Lead-based batteries are heavy, and their efficiency/service life is not in same level compared to lithium-based batteries. On the other hand, Lithium-based batteries are relatively expensive for now, because the price of the battery bank alone with the necessary control devices may cost the same as the other components of the solar power system combined. There are also other battery chemistries, which are not so common in commercial use in PV-systems such as Nickel Cadmium, *Nicd* and Nickel Metal Hydride, *NiMH*.

It is also reasonable to keep in mind that comparing different battery chemistries are not that simple, since there are a few matters to take in account. In Table 3 can be found a compilation related to different battery chemistries. The compilation was made by the author of this thesis using the

Handbook of Lithium-Ion Battery Pack Design publication by *John Warner* (Warner, 2015). The table presents the differences between battery chemistries. E.g., Lithium Ferro Phosphate's, *LFP*'s Specific energy is 2 – 3 times as big comparing the *Lead Acid*, *Li-ion* does not need a maintenance when *Lead Acid* requires every 3 – 6 months, while *NiCd* and *NiMH* require maintenance every 1 – 3 months. However, the price of a LFP battery would be 2,5 to 6 times larger compared to *Lead Acid*. In some contexts, the abbreviation *LiFePo4* is used instead of *LFP*, but they mean the same thing.

Table 3. Specification by Battery Chemistry (Warner, 2015)

Specifications	Lead Acid	Nickel Cadmium	Nickel Metal Hydride	Lithium Iron Phosphate	Lithium Manganese Oxide	Lithium Titanate
Chemistry descriptor	PbA/LAB	NiCD	NiMH	**LFP**	**LMO**	**LTO**
Specific Energy *(Wh/kg)*	30-40	40-60	30-80	80 - 130	105 - 120	70
Energy density *(Wh/l)*	60-70	50-150	140-300	220 - 250	250 - 265	130
Specific Power *(W/kg)*	60-180	150	250-1000	1400 - 2400	1000	750
Power density *(W/l)*	100	210	400	4500	2000	1400
Cell Voltage *(nominal)*	2V	1.2V	1.2V	3.2 - 3.3	3.8	2.2 - 2.3
Cycle life	300-800	1000-2000	500-1500	1000 - 2000	> 500	> 4000
Self-Discharge/month *(room temp)*	3-5 %	20%	30%	< 1 %	5%	2 - 10 %
Operating temperature	-20 to 60 °C	-40 to 60 °C	-20 to 60 °C	-20 to 60 °C	-20 to 60 °C	-40 to 55 °C
Cost (per kWh)	$150 - $200	$400 - $800	$200 - $300	$400 - $1200	$400 - $900	$600 - $2000
Maintenance Requirement	3-6 Months	30-60 days	60-90 days	Not required		

In Figure 3 (Brian J. Landi, 2009) can be found how the energy density goes together with Volumetric Energy Density in a form of visual presentation. The figure shows the Li-ion battery has the highest energy density while being the lightest of the bunch.

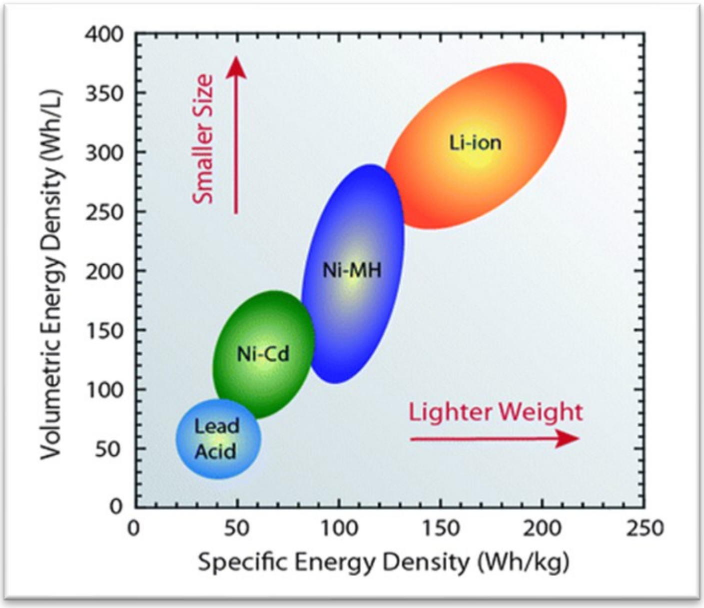


Figure 3. Energy Density Comparison (Brian J. Landi, 2009)

3 METHODOLOGY

3.1 The old PV system

In the premises there were PV-system installed with LiFePo4 batteries and working Solar Battery Management System, *SBMS*. Within the years the configuration has changed few times; In earlier years there were all four panels connected in the same system with 5 kWh *LiFePo4* batteries and suitable solar battery management system SBMS4080.

In 2018 and a part of 2019 there were two separate systems: The first one consisting of 3 solar panels á 195 Wp, 5 kWh *LiFePo4* battery bank, SBMS4080 plus 230 VAC inverter and the second one consisting of one 195 Wp panel, 5 kWh *LiFePo4*s and SBMS4080. The latter was used only to produce electricity for DC consumption devices such as, lightning for the different parts of house, and some outdoor lightning. The principle of the system with SBMS4080 is presented in Figure 4 (Electrodacus, 2014):

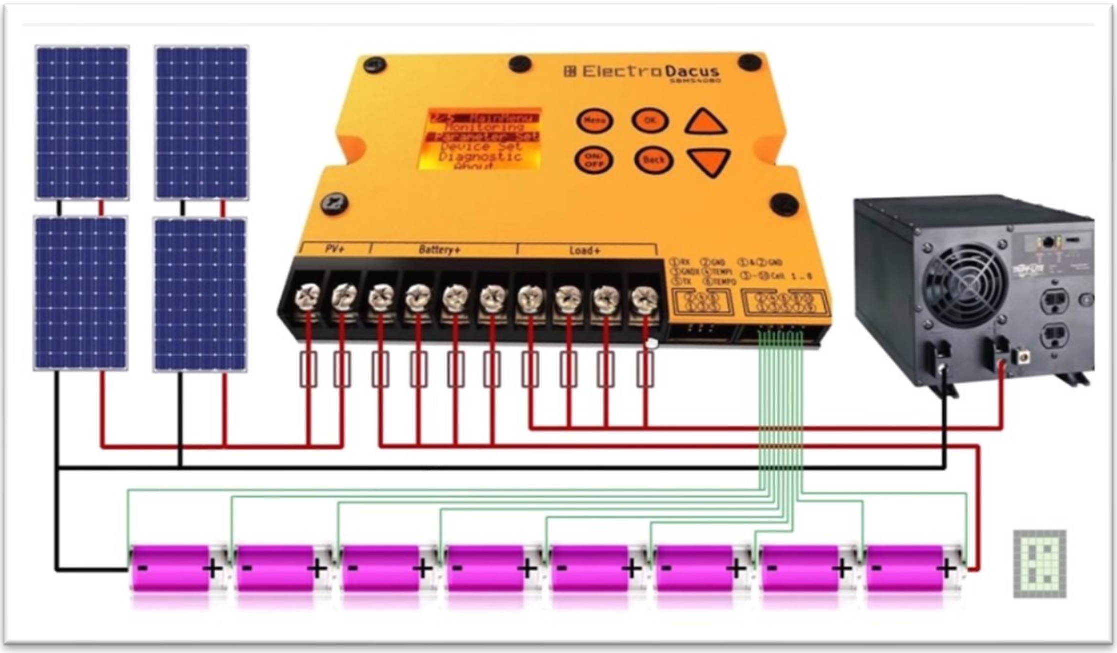


Figure 4. Simplified PV-system with SBMS4080 (Electrodacus, 2014)

A couple of figures below is presenting the setups from our system within the years. Figure 5 presents the earlies testing setup harnessing LiFePo4's. In the figure there is a Westech manufactured hybrid-inverter on the left. The inverter was so called "floor model" and its specifications was 2000W / 24 Vdc. The inverter also had a wired remote control that could be used to turn the inverter on or off. Unfortunately, I do not have a picture showing the switch. The inverter was recycled to my uncle and is still in use producing AC electricity from PV system's battery bank in their cottage in northern part of Finland.

Figure 5. SBMS4080 based system, 2015-2017 (Niskala 2015)

Figure 6. Testing setup in 2018, without finalizing touches
(Niskala 2018)

In the Figure 6 above, the test operation of the system was in progress. Afterwards, the installations were cleaned and made to look more aesthetic. On the upper left there is a hybrid inverter, two yellow SBMS4080's, opened connection box on the right, above the SBMS4080's a switch to select supply for DC load and between the inverter and switch there is a Raspberry Pi Single Board Computer, *SBC*. The cables and wires seen in Figure 6, except white ones are 24 Vdc cables. Although the picture of the test setup is messy, the white 230 VAC cables are installed in such a way that there is no risk of electric shock, i.e. they are contact protected, as 230/400VAC installations should be. Also, residual current protection devices were used, but they are not seen in the picture.

3.2 Solar electricity production data

In the initial phase of the project, we were in a situation where the system had been producing for some years, and there was also production information about the system, because over the years I had created a production monitoring system using the Round Robin Database, *RRD*. The *RRD* was running inside Raspberry Pi, *RPi*.

3.2.1 RRD (The old logging system)

The logging system built earlier was based on Round Robin Database (Oetiker, 2017). This is quite efficient tool for logging, however the configuration the one who has never coded barely anything, like me, was a bit complex. The database was configured for one year logging, and graph processing was integrated around this tool as well. Raspberry Pi gathered the data from the SBMS4080 by using *UART*, processed hourly, daily and monthly graphs as scheduled task. UART comes from: *Universal Asynchronous Receiver Transmitter*. In our system the database was configured for one year. This meant, because *RRD* is a circular database, after a year it started to overwrite the oldest data in the database. The graphs processed are presented in Figures 7, 8 and 9. For sharper images please look Appendix 1.

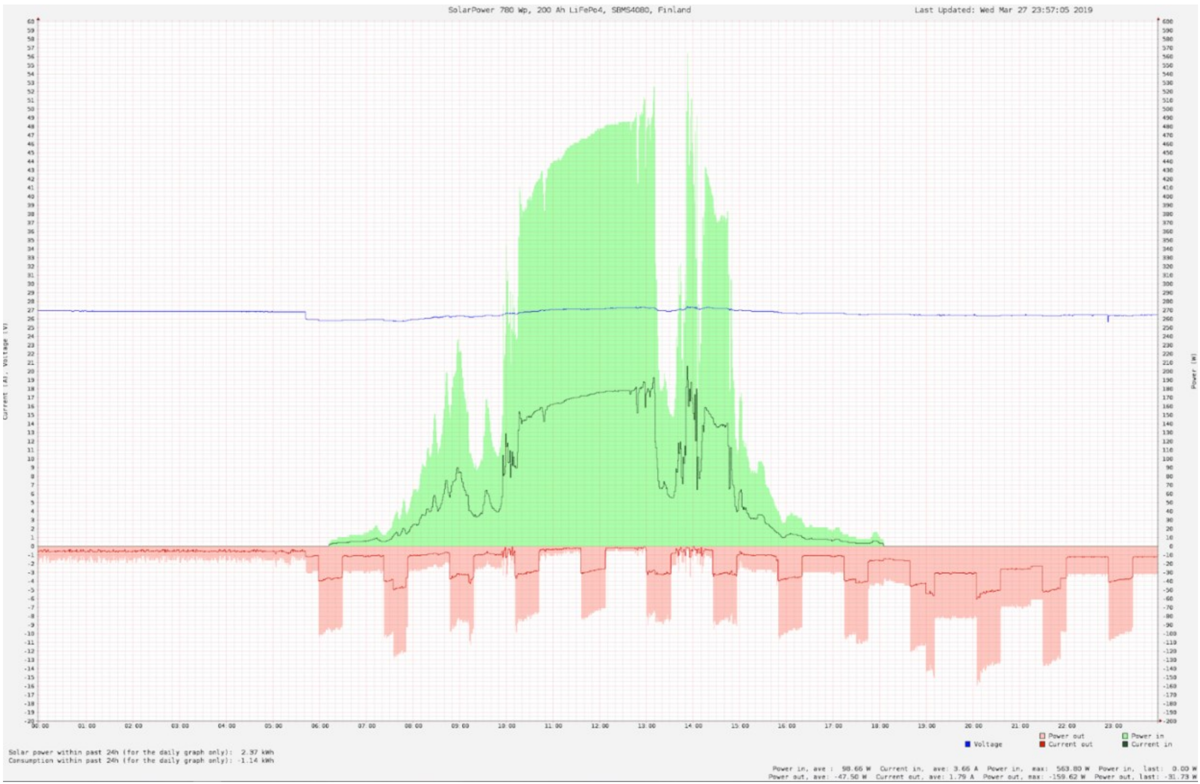


Figure 7. Daily graph, RRD (Niskala 2019)

Explanation related the Figure 7: The daily graph was processed from *RRD* every fifteen minutes and uploaded to the cloud. In this way, I stayed on the map of what the situation of the solar system was at any given moment, with sufficient accuracy in author's opinion. The script was created in a way that electricity production was drawn above the X-axis with green, and load below the axis with red. Also, there were blue thin line which presented the voltage of battery bank. On the bottom left in the graph can be seen the cumulative energy count from past 24 hours. On the bottom right there are average values from power and current as well as the maximum power.

Figure 8 show the weekly graph processed from the RRD. A noteworthy point in this graph is that the last 24-hour cumulative production value shown at the bottom left is not the correct value. In general, the weekly saved graph was more of a "nice to have" type printout, there was no real practical use for it. In the end, it was just fun fiddling around with the RRD tool and seeing what it could print.

Figure 8. Weekly graph, RRD (Niskala 2019)

In addition to the two graphs above, there were also a monthly graph processed. However, using the monthly chart was even more trivial than the previously mentioned weekly chart. The monthly graph is shown in figure 9.

Figure 9. Monthly graph, RRD (Niskala 2019)

3.3 Determining the size of new PV-system

3.3.1 Electricity production data as a base

Like mentioned earlier, there were logging data available for research and calculation. The challenge of this data was the thing that the PV-system configuration altered within the years, and data gathered was from different size of systems. The data was researched carefully, and I concluded that the production data from the year 2016 and 2017 was all collected from the entire four-panel system, and thus this data has been used as the backbone of the calculation and determination of the size of new PV-system. However, from the year 2016 logging data there were usable only data between July – august, but year 2017 there were whole year data usable.

In year 2016 the 4-panel á 195 Wp system produced in July 61,36 kWh and August 64,14 kWh. In this year there were no other months logged. The average production in above mentioned months was then 62,72 kWh/month.

In year 2017 there were a much more data stored. The production and consumption of the year 2017 can be seen in Table 4. The data is obtained from Appendix 2, Data and calculations.

Table 4. The production and consumption of the year 2017

Month	**Production (kWh)**	**Consumption (kWh)**
January	1,65	0,95
February	8,20	8,81
March	40,01	39,77
April	53,35	46,10
May	76,32	76,60
June	61,76	63,53
July	70,51	71,94
August	33,75	41,88
September	28,40	28,72
October	6,75	6,23
November	0,34	1,94
December	0	0
The sum of the year	381,06	386,48
Average / month	31,75	32,21
Average, March – August	**55,95**	56,64

More detailed data can be found in Appendix 2 such as, daily production and consumption.

3.4 The car of this project

There was a car involved in this project which, at the time of publication, the undersigned thought was ahead of its time. At the time, the car in question wasn't sold very much in Finland, but these days it is popular for its technology and price. The car is an GM-manufactured Opel Ampera, which was manufactured between 2011 and 2014. The car has two electric motors, one of which also acts as a generator when the batteries are empty. The generator is run by a 1.4-liter gasoline engine. The car runs practically all the time on electricity, even when the batteries are empty. And when they are empty, the generator only produces electricity, which is transferred to move the car with the help of an electric motor (auto.data.net, 2012). In Figure 10 the structure of the car is presented (GM, 2011).

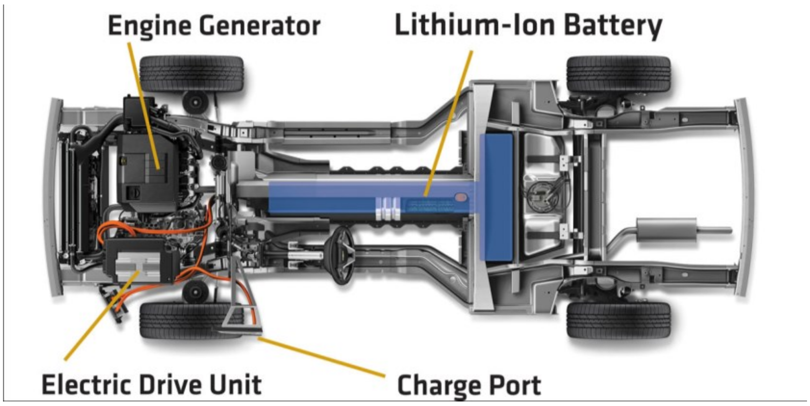


Figure 10. Opel Ampera and Chevrolet Volt structure (GM, 2011)

The Ampera is basically the same car as Chevrolet Volt MY 2011 - 2014, but with slightly different looks from the front and rear. Ampera is created for the European market, while the Volt is for North America. Below in Figure 11 is the car related to this project.

Figure 11. Opel Ampera, MY 2013 (Niskala 2020)

During the project, the car was also "updated", and the Ampera was replaced by the second-generation Chevrolet Volt. The second-generation Volt, on the other hand, is quite different in appearance from its predecessor, and offers updated technology with a larger driving battery. The second-generation Volt was never officially released in Europe, and it was manufactured only between 2016 and 2019. The generation 2 Volt is shown in Figure 12.

Figure 12. Chevrolet Volt, MY 2016 (Niskala 2022)

3.4.1 Car efficiency

In general, the efficiency can be determined if the input energy/work and output energy/work of the system are known. The efficiency is calculated by using Equation 1:

$$efficiency = \frac{Wout}{Win} \quad (1)$$

In this case the *Wout* is the amount of electricity used to move a car, and *Win* is the amount of electricity flown from the wall plug towards the car battery.

The efficiency in this matter there are two things to take in account. The first is the efficiency related to electricity used to move a car. The second is the efficiency of car charger.

As mentioned earlier, during the project I had two different E-REV's, Opel Ampera and Chevrolet Volt Gen 2. Before taking steps towards the PV-system calculation, I used the efficiency in these related to car I had in the beginning. The car was Opel Ampera MY2013.
The Ampera had an average charging efficiency factor 0,84. This value was determined by noting previous used electricity from car's information display and measuring the electricity during charging by using an ABB C11 electricity meter installed in the estate's electrical system. A part of measurement was made in August while charging car outside over the night, and other parts in September while charging car in the garage over the night. For example, the car consumed 12.8.2020 7,7 kWh and charging the battery of the car consumed 9,25 kWh, the efficiency calculated by using equation 2:

$$car\ efficiency = \frac{7{,}7\ kWh}{9{,}25\ kWh} = \mathbf{0{,}83} \quad (2)$$

A couple of measurements were made, and an average value was determined. The measurements related to charging efficiency can be seen in Table 5:

Table 5. Ampera charging efficiency (Niskala 2020)

Ampera car charging efficiency			
Date	**Used kWh**	**Charged kWh**	**Eff**
08/08/2020	10.5	12.68	0.828
09/08/2020	11	13.76	0.799
12/08/2020	7.7	9.25	0.832
16/08/2020	10.6	13.01	0.815
01/09/2021	8.6	9.3	0.925
10/09/2021	10	12.1	0.826
		average	**0.84**

The other efficiency, meaning how far car did go with 1 kWh of electricity, was gathered by using *MyGreenVolt* android application from Google Play market. The application is also available for Apple products. A few words about the application before heading forward with the efficiency. I have used MyGreenVolt -app often I've jumped into car to start driving. The application is connected to the car via Bluetooth and can display real-time data, as well as save it for later analysis. The application shows in real time, among other things battery, electricity system and *ICE*'s temperatures, instantaneous power, how much electricity has been used while driving, a pie-type chart of how the electricity consumption is distributed in a car between powertrain, heating and other loads. Also, it is possible to examine driving battery's cell voltages, daily mileage, consumption, fuel usage and battery temperature etc. Very useful application for a character like me. Figures below is just for an example since it is from recent car, Chevrolet Volt logging. Figure 13 presents the window where e.g., the real time values are shown, Figure 14 shows the efficiency window and Figure 15 Daily electricity consumption.

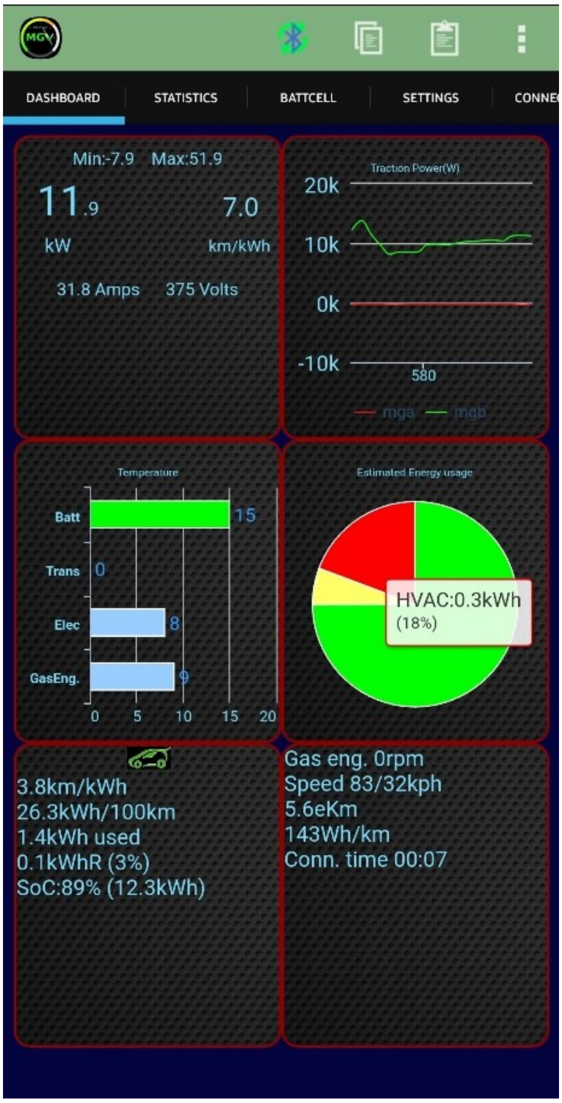


Figure 13. MyGreenVolt, realtime window (Risacher, 2020)

Figure 14. MyGreenVolt, efficiency (Risacher, 2020)

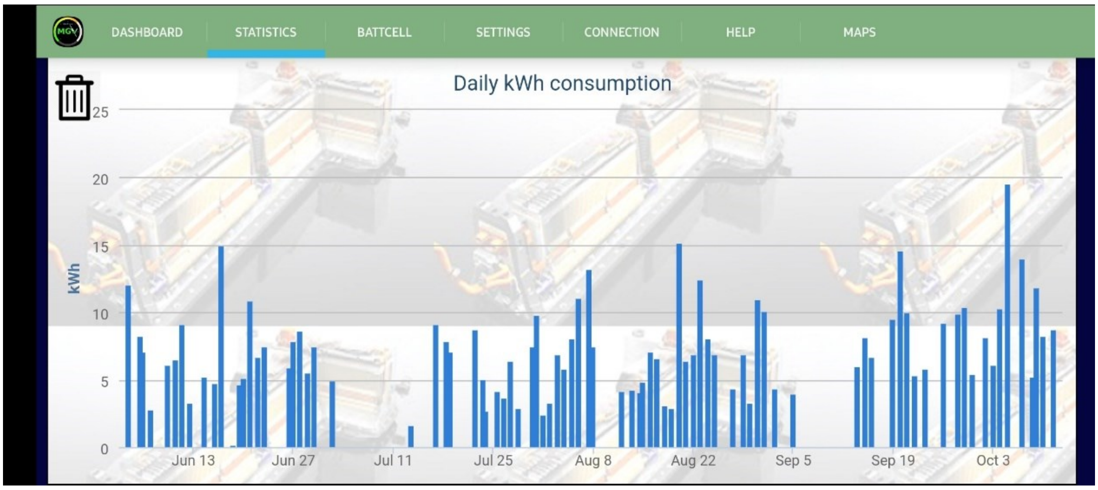


Figure 15. MyGreenVolt, Daily kWh (Risacher, 2020)

Back to the efficiency. The Ampera had an average 6,225 km/kWh, which was determined by logging numerous drives in 2020 by using MyGreenVolt -app. The data can be seen in Appendix 3, Car efficiency. To get forward with calculations we convert above mentioned value to kWh/km, which can be done by creating an inverse value by using equation 2:

$$\text{Consumption/km} = \frac{1}{6{,}225\ km/kWh} = \mathbf{0{,}1606}\ \boldsymbol{kWh/km} \qquad (3)$$

, which is the electricity consumption per one kilometer.

Based on above mentioned, we can now calculate how much electricity is taken from the wall plug into the car’s driving battery. Car consumes 0,1606 kWh/km and charging efficiency is 0,84 the overall the consumption, *Win* is calculated by using equation 4:

$$\text{Win} = \frac{0{,}1606}{0{,}84} = \mathbf{0{,}191}\ \boldsymbol{kWh/km} \qquad (4)$$

This value will be used further in next chapter, The size of the new system.

In Figure 16. you can see the car dashboard after one day drive. As seen in the figure below, the car information display shows that car consumed 8,4 kWh, while the driven distance was 48 km. As an example, we can calculate the consumption per one kilometer by using equation 5:

$$\text{Consumption/km} = \frac{8{,}4\ kWh}{48\ km} = \mathbf{0{,}175\ kWh/km} \qquad (5)$$

Figure 16. E-REV's information display, distance and energy used (Niskala 2020)

An interesting matter appeared when I took a closer look into the Appendix 3 and the efficiencies of two different cars. From the values collected by the application, it seems that GM has significantly improved energy efficiency. While the average efficiency of the Ampera was 6,225 km/kWh, it is 7,896 km/kWh with the Chevrolet Volt. By using equation 6, we can calculate percentual development of efficiency:

$$\text{Eff increase} = \frac{7{,}896\frac{km}{kWh} - 6{,}225\frac{km}{kWh}}{6{,}225\frac{km}{kWh}} * 100 = \mathbf{26{,}84}\ \% \qquad (6)$$

We are talking about almost 27 % increase of efficiency according to my own measurements. A summary is shown in Figure 17. More detailed values related this can be found in Appendix 3.

Ampera average **6.225 km/kWh**
Chevy volt average **7.896 km/kWh**

Figure 17. Ampera and Volt efficiency (Niskala 2022)

3.4.2 The size of the new system

By taking in account the things mentioned in previous chapter, the consumption of the car within working day with electricity transformation losses included, is calculated by using equation 7:

$$\text{Consumption/48km} = 48\ km * 0{,}191\ kWh/km = \mathbf{9{,}168\ kWh/km} \tag{7}$$

This amount of energy would be needed to produce by the new PV-system in every working day. Also previously were mentioned how the old system was performing back in the days. The average production per month between April to August, shown in Table 4 was 55,95 kWh per month. This means that if car does not move in the weekend, the energy should be available for 21 working days of the month. The amount of energy available in 21 working days calculated by using equation 8:

$$\text{Energy available / working day} = \frac{55{,}95\ kWh}{21\ d} = \mathbf{2{,}664\ kWh/d} \tag{8}$$

In addition to this, we need to take in account the inverters efficiency as well since the car only approves AC electricity.

However, related to inverter efficiency measurements and calculations, I made some measurements in 2020, but these weren't used when calculating the size of the new system. I do not have an answer why this happened, but in calculations I used the value 0,95. This is probably the sum of many factors, one of which presumably is that in those days at work a lot of motor drives and reactive powers were calculated. In matters related to the work, the cos(phi) value appearing on the value plates of the devices, which are used to calculate the reactive power, was studied. The values appearing on the plates "stuck in my head", and thus I have erroneously used the average cos(phi) value used in frequency converter drives when determining the efficiency of the inverter. Next, I will present the way in which I calculated the effects of inverter efficiency on electricity production using an efficiency factor of 0,95.

Previously was brought up that there would be 2,664 kWh DC energy available in a working day from the old PV system. By multiplying this with inverter efficiency 0,95 by using Equation 9, I got the AC electricity produced per working day:

$$2{,}664\ kWh/d * 0{,}95 = \mathbf{2{,}531\ kWh/d} \tag{9}$$

This way I determined how much electricity was obtained from old PV-system with conversion losses during working day. Once the above-mentioned matters were known, the size of the new system could be calculated.

The way to my workplace is 22 km/side and often when coming back to work more kilometers is needed to drive e.g., to pick up my kids. Therefore, I estimated in addition 4 km/day. The calculation is shown in equation 10:

$$22\ km + 22\ km + 4\ km = \mathbf{48}\ \frac{\boldsymbol{km}}{\boldsymbol{working\ day}} \tag{10}$$

The car consumed 0,191 kWh/km as an average, and consumption per 48 km was already presented earlier in equation 7, which was:

$$48\ km * 0{,}191 = \mathbf{9{,}168}\ \boldsymbol{kWh} \tag{7}$$

Four panel PV-system produced electricity in such a way that it would have enabled 2,527 kWh of AC electricity to be transferred to the car per working day. So, in order to produce 9,168 kWh, I calculated how many times larger the new system needed to be by using equation 11:

$$\frac{9{,}168\ kWh}{2{,}531\ kWh} = \mathbf{3{,}622}\ \boldsymbol{times\ larger\ system} \tag{11}$$

Rounding up the value 3,622 and multiplying the old system's calculated production per working day by using rounded value 4, I got the electricity production needed per day by using the value calculated in Equation 9 and putting these to Equation 12:

$$2{,}531\ kWh * 4 = \mathbf{10{,}124}\ \boldsymbol{kWh} \tag{12}$$

This was a base how I calculated how large the new PV system needed to be. It should produce AC electricity so, that 10,124 kWh would be available every working day.

I mentioned earlier that I used the assumed value 0,95 as the efficiency factor for calculating produced AC electricity, when I should have used an average value, I got based on the measurements. The inverter efficiency is determined by using five different measurements in different days. The average value based to measurements is 0,886. This means that transforming certain amount of DC electricity to AC electricity, 11,4 % of the energy will transform into something else, basically into heat. The inverter efficiency measurements and calculations can be seen in next page in Table 6.

Table 6. Inverter efficiency measurements

Date	Electricity from the battery (kWh, DC)	Electricity from the inverter (kWh, AC)	Efficiency factor
12.3.2020	6.135	5.406	0.881
13.3.2020	5.337	4.83	0.905
24.3.2020	8.089	7.146	0.883
11.4.2020	6.172	5.608	0.909
20.4.2020	6.301	5.381	0.854
		Average	**0.886**

Since the calculations related to inverter's efficiency were performed in a way as told earlier, let's look how badly I went wrong in calculations. I calculated the AC output of the old system earlier according to the Equation 13:

$$2{,}664\ kWh * 0{,}95 = \mathbf{2{,}531\ kWh} \tag{9}$$

When I should have used an efficiency factor based on measurements shown in Table 6, to determine the AC output. Expressed in the equation 13:

$$2{,}664\ kWh * 0{,}886 = \mathbf{2{,}360\ kWh} \tag{13}$$

The difference in electricity production of the old system based on these comparative calculations is according to equation 14:

$$2{,}527\ kWh - 2{,}357\ kWh = \mathbf{0{,}17\ kWh} \tag{14}$$

And reflecting this to the size of the new system, which calculated to be four times bigger as the old system, we get to see the effects between two different calculations in Equation 15 below:

$$0{,}17\ kWh * 4 = \mathbf{0{,}68\ kWh} \tag{15}$$

This means that the electricity production by the new system were 680 Wh more optimistic comparing the calculated where I used assumed inverter efficiency factor 0,95.

3.4.3 Datasheets for solar panels, reflecting to calculation

In the meantime, a few comments about how solar panel power values are generally informed, and why I determined the size of the new system according to the above.

Usually, the power of the solar panels is informed as *Wp*, which stands for peak watts. This value is determined as maximum instantaneous power of the panel in Standard Test Conditions, *STC*. In *STC* the irradiance is 1000 W/m^2, on a perpendicular surface when in real world it is location and installation angle dependent. So, the peak watts don't tell much how the panels perform in certain environmental and installation conditions, e.g., in a location where our house is located. Therefore, my approach was, that I did not focus on peak watts indicated by panel manufacturers. I focused my own production loggings instead when determining how large the new PV system needed to be in the location we live. Peak watts are just a sales pitch that has no contact with reality when talking about the electricity output of a solar system in real life.

One another thing to notice is that in real life the surface temperature of the panels are hotter than in *STC*, which practically means that the panel produces less electricity when the surface is hotter. When looking the datasheets of solar panels, there is also Temperature Coefficient value mentioned. This value determines how the power of the panel decrease, when the surface temperature increase. E.g., the datasheet for our old panels indicates that the temperature coefficient is -0,47 %/°C, which means that when panels surface temperature increases one Celsius, the power of the panel decreases 0,47 %. So, when reflecting this into real life the normal operating temperature in warm sunny days is closer to 60 °C, which is 35 °C higher than in *STC*. This means that e.g., 200 Wp panel power in normal operating temperature is according to Equation 16 below:

$$35 * 0{,}47\ \% = \mathbf{16{,}45}\ \%\ \boldsymbol{smaller} \qquad (16)$$

Also, the solar irradiance on the earth's surface is location dependent and needs to be considered. So, in theory, let's say, the irradiation would be 20 % smaller than in STC, and taking panels temperature coefficient into calculation formula, according to Equation 17, the 200 Wp panel would be closer to:

$$200\ Wp - \left(200\ Wp * (20\ \% + 16{,}45\ \%)\right) = \mathbf{127{,}1}\boldsymbol{Wp\ panel\ in}\ "\boldsymbol{real\ life}" \qquad (17)$$

Figure 18 in the next page is presenting temperature coefficient of our old panels.

TEMPERATURE COEFFICIENT

Temp. Coeff. of Isc (TK Isc)	0.042 %/℃
Temp. Coeff. of Voc (TK Voc)	-0.336 %/℃
Temp. Coeff. of Pmax (TK Pmax)	-0.47 %/℃

Figure 18. ETSolar temperature coefficient (ETSolar)

I researched many different panels and ended up purchasing almost the same type of the panels that I had. The old panels were *ET Solar ET-M572195*, shown in Figure 19, and the selected new panels were *Luxor Eco Line M72/200*, shown in Figure 20.

Figure 19. 195 Wp panel (ETSolar)

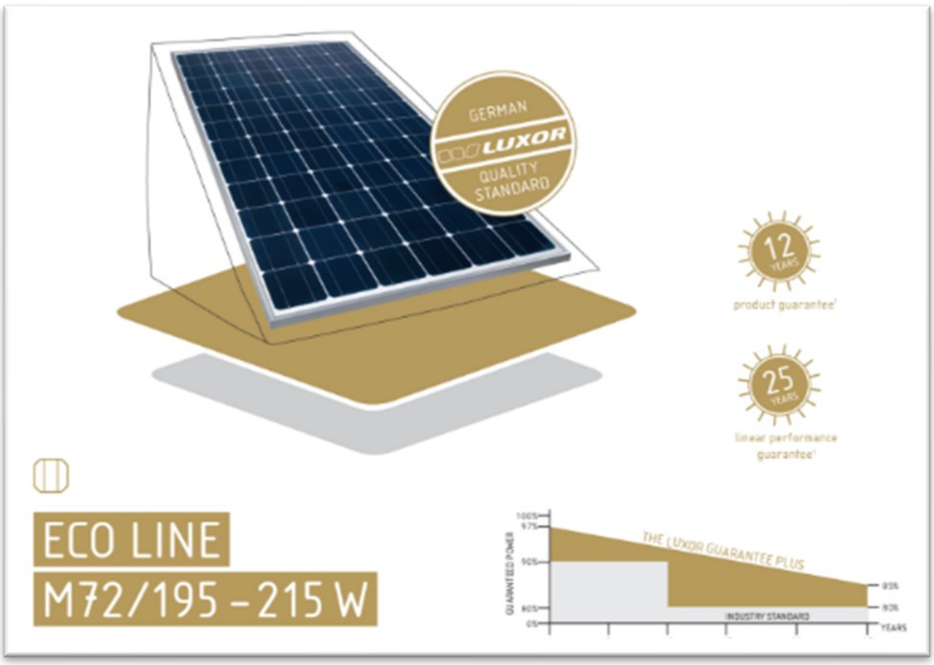


Figure 20. 200 Wp panel (Luxor Solar)

3.4.4 The selection of panels and structural solutions

The reason why I chose these panels was that their 12-piece assembly fit well on the roof of the garage. The physical dimensions, made it possible to integrate the panels well into the roof of the garage. The size of the panel field was thus approximately 6.3 m * 2.4 m. The panel configuration can be seen in Figure 21.

Figure 21. The panels on the roof of garage (Niskala 2022)

Everything seemed well ”on the paper”, and now they are installed “in” the roof. In the installations and the implementation solution, attention was also paid to the fact that the panels integrated into the ceiling would not get too hot during use. This was done by making a window-shaped ventilation grill at the end of the garage. At the same time, the inner roof of the garage's canopy section and the wooden boards located under the eaves were installed in such a way that the air could move as well as possible. Figure 22 shows a bit more related this matter.

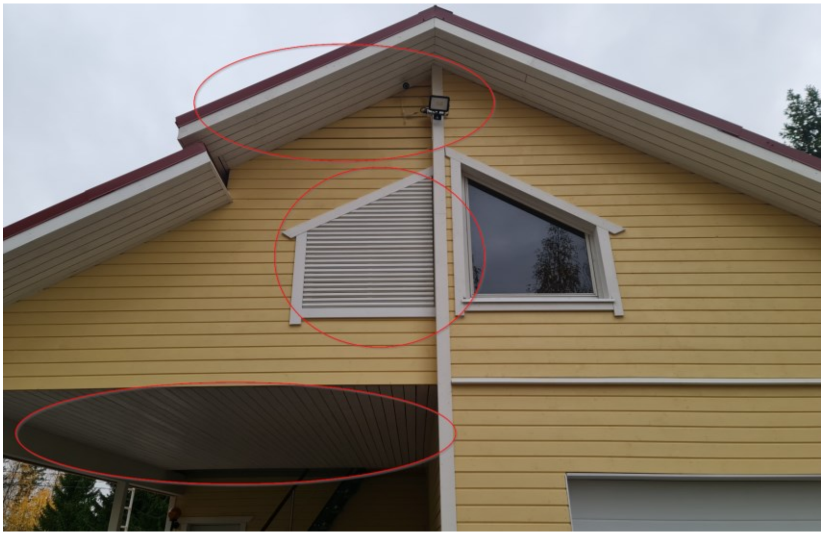


Figure 22. The "ventilation" of the panels (Niskala 2022)

3.4.5 The Solar Battery Management System (SBMS)

The *SBMS4080* which had been in use for a couple of years, had proven to be quite a capable device. Since I had those LiFePo4 batteries in use, I did not manage to find reasonable alternatives to control battery cell balancing by using other type of devices. Many manufacturers support certain type of batteries as a part of the systems, but there is their own communication protocol between batteries and BMS which did not fit well considering the already existing equipment base. By this reason I decided to go with new version of *Electrodacus* Solar Battery Management System.

The old battery management system was Electrodacus *SBMS4080*, which was in use from the year 2014. The new SBMS is the successor of the previous model, and the exact model is *SBMS0*. The old and the new SBMS can be seen in figures 23 and 24.

Figure 23. SBMS4080 (Niskala 2020)

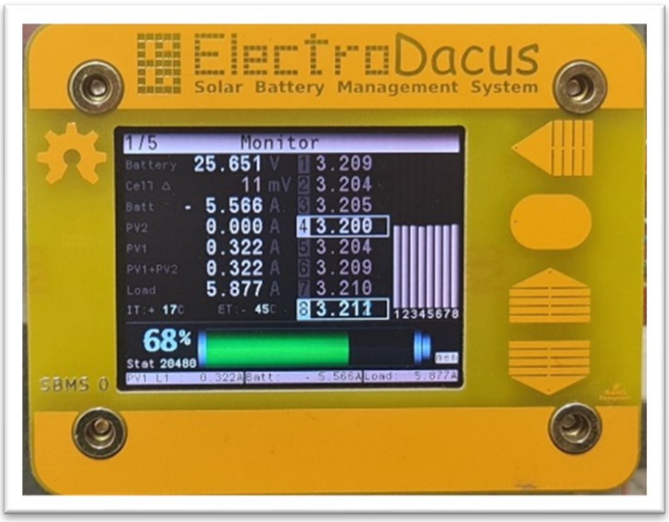


Figure 24. SBMS0 (Niskala 2022)

The new SBMS0 differs from its predecessor, among other things, in that the energy coming and going from the batteries does not flow through the device itself, but the system includes small voltage converter *DSSR20*, shown in Figure 25 that are controlled by the *SBMS0*.

Figure 25. DSSR20 (Electrodacus, 2014)

Solar Battery Management System, SBMS is a solar charge controller designed to replace the Lead Acid batteries and solar charge controllers most people use today in Offgrid, Boats and multiple other applications with 12V and 24V systems. Solar BMS can be used with 3 up to 8 Lithium cells in series (any type) or even supercapacitors. Any number of parallel cells are no different from a single larger capacity cell so it will just count as one. The new SBMS0 plus DSSR20 is replacing all other models and can handle up to 30kW of solar PV using multiple DSSR20 (Electrodacus, 2014).

Princinple of the Electrodacus SBMS0 system is shown in Figure 26.

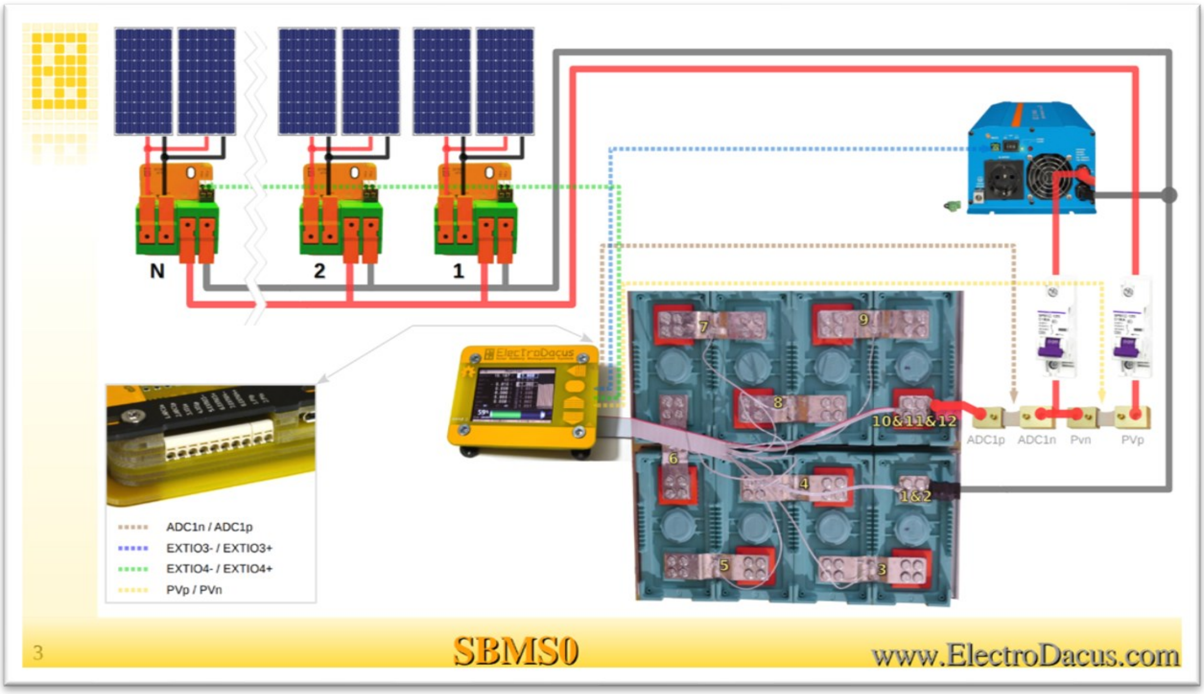


Figure 26. SBMS0 based system (Electrodacus, 2014)

Like said, the *SBMS0* is more like controller and lithium - based batteries need to have protecting device to prevent over- and undercharging. The SBMS0 controls the current flow coming from the panels via DSSR20's. Some explanations related to Figure 26 above: Green dotted line is presenting the control line from SBMS0 to DSSR20. Devices acting as a load, for example inverters are also controlled by the SBMS0 as well, which cut off the load when the battery charge level is low. The control line of the load is presented as blue dotted line in Figure 26. The dotted lines in same figure are, Brown = energy flow information from current measurement shunt of the battery, Yellow = energy flow information from current measurement panel shunt.

3.4.6 The inverter(s)

I researched alternative option as well such as *Victron Multiplus* -series. Victron is known for its high-quality and widely used products. However, the price range is relatively high and bigger hybrid inverters are mostly 48 Vdc – inverters. Our system, especially SBMS does not support 48 Vdc systems and I decided to go the way that I purchased another 3000 VA 24 Vdc hybrid-inverter to be installed side-by-side with the old one.

In the figures below is presented the inverters of the system. In Figure 27 the old inverter is presented. The model is *MPP Solar PIP 2424HS (3000 VA / 2400 W)*.

Figure 27. MPP Solar PIP 2424HS (Niskala 2022)

The new inverter is *EASUN Isolar SPS 3KW*, and is shown in Figure 28.

Figure 28. EASUN Isolar SPS 3kW (Niskala 2022)

3.4.7 Battery configuration

The old setup was divided to two different battery banks: 8 pcs of 200Ah LiFePo4 cells in each. For the new system I combined these cells as a one 24 Vdc / 400 Ah battery pack. This was done by creating "super cells" by connecting two of the cells in parallel. In this way, the nominal voltage of the cell remains the same, but the current and capacity increase. The eight "super cells" were then connected in serial to achieve approx. 24 Vdc nominal voltage for the system.

The battery assembly and SBMS0 balancing cable principle with gray lines are shown in figure 29.

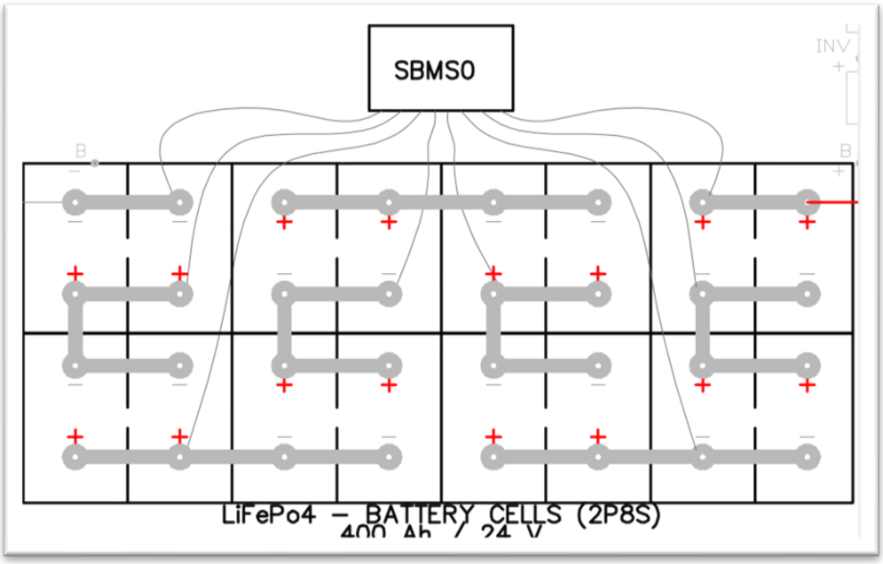


Figure 29. 2P8S battery and SBMS0 (Marko Niskala 2020)

Figure 30 is showing a full battery pack consisting of 16 pcs of 200 Ah *LiFePo4* cells in 2P8S configuration and in Figure 31 presents closer view how the balancing wires are connected into the cells.

Figure 30. The battery pack (Marko Niskala 2022)

Figure 31. LiFePo4 balancing wires (Marko Niskala 2022)

As you see in the princible in Figure 29, the *SBMS0* is wired to every supercell. The *SBMS0* need to be aware of the status of every individual cell at all the time. Safety limits can be entered through the SBMS0 device, based on which it controls charging and load.

The parameter settings menu included values for LiFePo4 cells already. All I needed to do was to change the battery capacity to 400 Ah. There are many of paramaters / values in the menu such as, safety limits, under- and over voltage limits and delays, cell balance tolerances, battery capacity, etc. These values determine, for example, how the battery is protected and how precisely the battery cells are kept in balance. In Figure 32 is shown parameter setting menu.

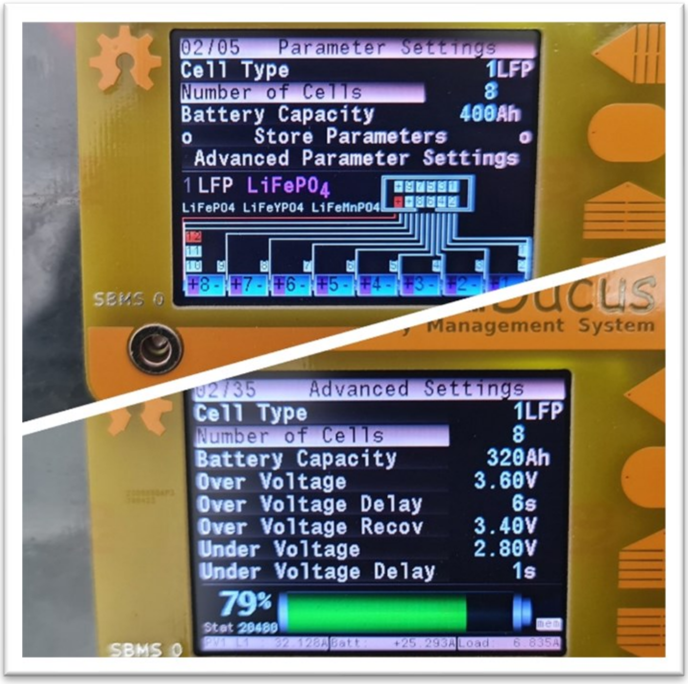


Figure 32. Parameter settings menu (Niskala 2022)

Most usable menu for me is the one showing instantaneous values. In Figure 33, explaining the values from up to down: There are values of Battery voltage, cell delta V, Battery current, PV2 current, PV1 current, the sum of PV1 and PV2 currents. Also individual cell voltages are shown on the right.

Figure 33. SBMS0 monitoring window (Niskala 2022)

It is possible to control two separate panel fields with the device, which is why PV1 and PV2 appear in the menus. In our system, all panels point in the same direction, so I don't think it's necessary to use this feature, and I haven't really looked into it in detail. Personally, I would see the need for that feature if there were clearly two separate panel fields pointing in different directions.

Another monitoring window is showing the cumulative values of the system. Separate rows for the *PV*s, *Battery*, *PVtoLoad* and *BattLoad*. The *PVtoLoad* is cumulative value for electricity flown directly from panels towards the load and the *BattLoad* is cumulative value from electricity flown from the battery to load. The values are shown kiloampere hours as well as kilowatt-hours. Shown in Figure 34.

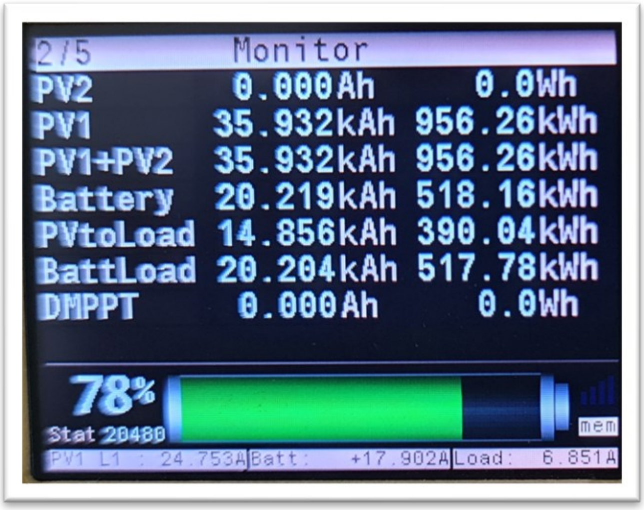


Figure 34. Cumulative counter (Niskala 2022)

3.5 Test setups within the project

Within the project different setups were tested.
The first test setup was the way that old panels consisting of 4 * 195 Wp, were configured to work with two new panels, á 200 Wp. By installing this setup, I got a change to study how new *SBMS0* and devices related worked. Everything seemed to be working fine.

In next phase I added two more panels in the system. In the next page you can find a main diagram from that test period divided in four different figures. The full diagram can be seen in Appendix 4, Main Diagrams.

Figure 35 shows the section of the panels. The panels are in two three panel groups, and one two panels group. The wires coming from the panels to group fuse, e.g., 1F1 and from the fuse going towards the DSSR20.

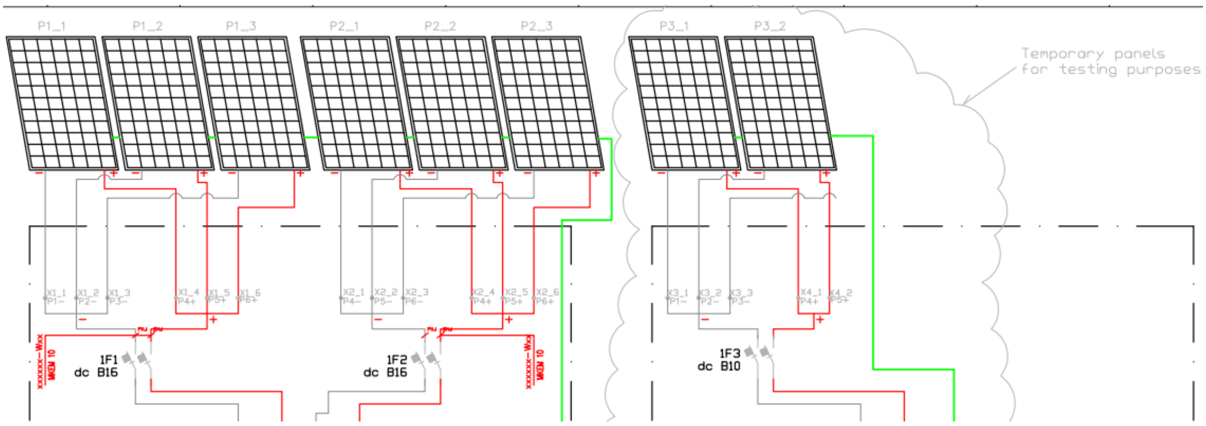


Figure 35. Test setup main diagram part1 (Niskala 2020)

Figure 36 shows the DSSR20’s, which are also used to adjust the voltage more suitable for the system. DSSR_1 and DSSR_2 are connected to the wires coming from three panel groups, the DSSR_3 was for one 2 panel group.

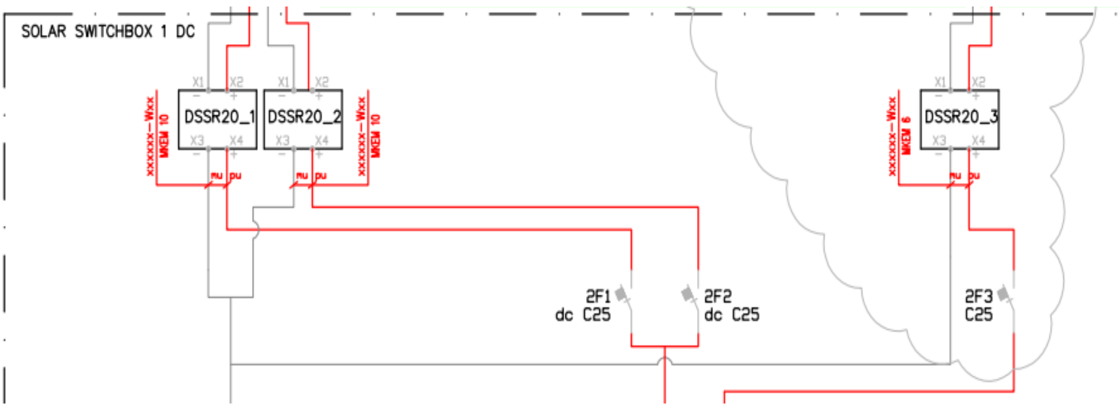


Figure 36. DSSR20's (Niskala 2020)

Figure 37 is presenting the battery bank and a small 24 Vdc / 600 W inverter I was using to supply electricity to freezer and one small circulating water pump.

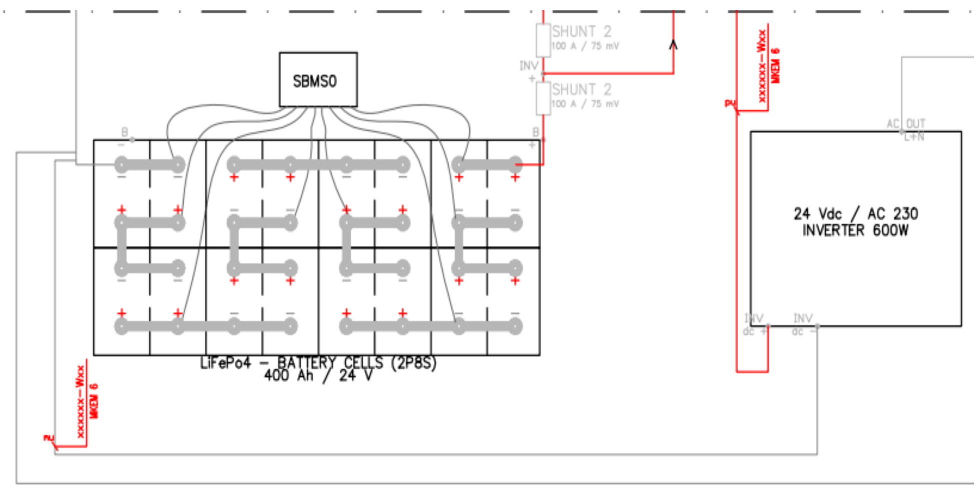


Figure 37. Battery bank and small inverter (Niskala 2020)

Figure 38, the last section of testing phase main diagram shows more related to electricity distribution. There is the other inverter connected to Grid selection switch, and after the switch the electricity is distributed to different locations. Note, that 16F1 was residual current circuit breaker even the drawing symbol tells something else.

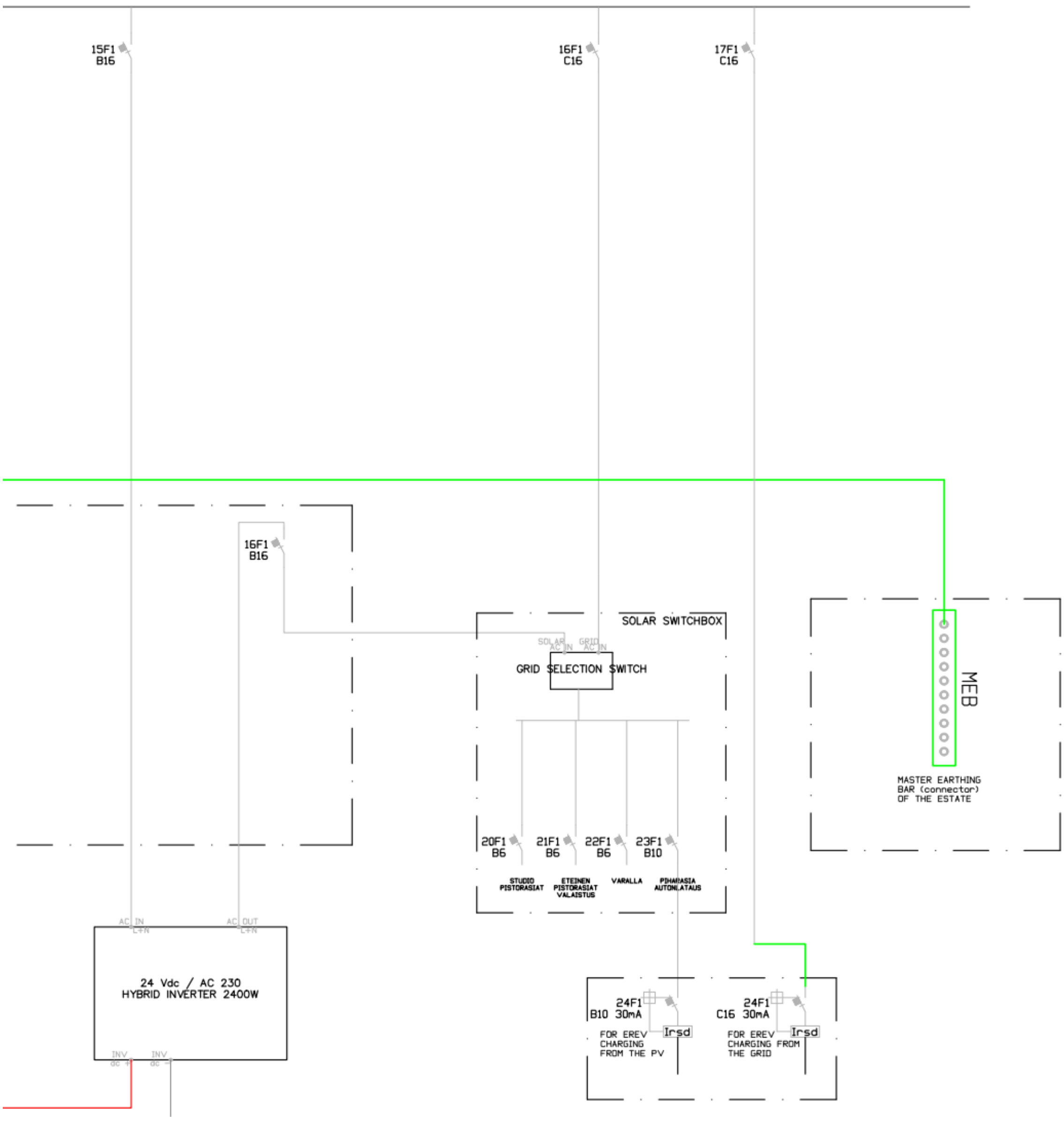


Figure 38. Electricity distribution (Niskala 2020)

The testing setup nro 2 panels can be seen in Figure 39.

Figure 39. Testing setup nro 2 (Niskala 2022)

3.6 Data logging system and measurement methods

The new logging system is built by using Raspberry Pi as well. It differs from the SBMS4080 in a way that in SBMS0 the *UART* is readable thru USB-port and in SBMS4080 there were two pins where wires connected. In addition, the SBMS0 is equipped with Wi-Fi, but if UART is in use, the Wi-Fi is disabled. If desired, Wi-Fi can be used for logging purposes as the SBMS0 acts as an *AP* (Access Point) and will deliver data to a Wi-Fi enabled computing device that supports *HTML5* capable web browser such as, a smart phone, tablet or laptop (Electrodacus, 2014).

I ended up the way that did not use *RRD* this time since I thought it would be enough just to log production data regularly and achieve some estimation of the system's status "on-the-go". Even I decided to go "easy" on this and not to configure RRD, I needed to re-study python programming in a new perspective; The selected battery management system provides UART connection, but differences comparing the old SBMS is that the serial data feed flowing thru the UART is encrypted. To get the stream into readable format I needed to create a code which included decryption script. In *SBMS0* manual there was encryption script mentioned, but it was not for python programming language. Eventually I managed to find reasonable encryption script where to start and modified it to suit the project. The code is located at the beginning of whole logging script. In the same python code is the calculation part and saving to csv file -part. The code is scheduled to run by using *cron* (Adminschoice.com, 2022). Also, there is one more script which run every fifteen minutes to upload momentary values of the system into the google drive.

I'm not so expert to explain what everything exactly means, but I'll try. In Figure 40 is shown a first part where, such as serial, time and csv modules are imported.

```
#!/usr/bin/env python3
# -*-coding:utf-8 -*

import os
import serial
import time
import sys
import re
import csv
import datetime
```

Figure 40. Python, modules (Niskala 2022)

The serial stream fed thru the USB port is encrypted, and for this we needed decoding. The script's base part of the decoding can be seen in figure 41. Also, there are rows with # sign, which means that those rows are comments and does nothing else except explains things. The base idea of the decoding script is to define where in the string the wanted character / data is, and then decode it into readable format.

```
##############################################################
##############################################################
# p - location of the data in the string, starting at 0!
# s - size of the data (for example, SOC is 2)
# d - the name of the variable in this case var sbms
def dcmp(p, s, d):

    xx = 0;

    for z in range(s):
# Java script: xx = xx + ((d.charCodeAt((p + s - 1) -z) -35) * Math.pow(91, z$))
#         wanted_ascii_character = ord(d[(p + s - 1) - z]) #python 2.x
     wanted_ascii_character = d[(p + s - 1) - z] #python3

     xx = xx + ((wanted_ascii_character - 35) * pow(91, z))

    return xx
```

Figure 41. Python, decoding base (Niskala 2022)

Next thing is to define hardware, in this case where the USB connected *SBMS0* is located, transfer speed for data exchange, filename for temporary files where the data is stored. These can be seen in Figure 42 below.

```
SBMS = "/dev/ttyUSB0"
ser = serial.Serial(SBMS, baudrate = 115200, timeout = None)
while True:
    stream = ser.readline(None)
    print (stream)
    filenamel = time.strftime("%Y%m%d")
   # with open(filenamel + '_SBMS' + '.csv', 'a') as f: f.write(read)
    with open("SBMStest_rawfile.csv", "ab") as f: f.write(stream)
    with open("SBMStest_compressedbckup.csv", "wb") as f2: f2.write(stream)
#ser.close()
```

Figure 42. Python, hardware and temporary csv's (Niskala 2022)

Then the decoding continues. The length of the stream is 61 characters, and first thing in this part is to check the length and then proceed with decoding. For example, the *SOC* is in the stream six characters away from the beginning of the stream and is two characters long, while battery current value is located 29 characters away and is 3 characters long. These can be seen in figure 43 and 44.

```
    # process the stream
    if len(stream) == 61:
      SOC = float(dcmp(6, 2, stream))
#      print("PV SOC = " + str(SOC) + "%")

    # one of cell voltage has to be cast to a float
      Cell1 = float(dcmp(8, 2, stream))
#     print('Cell1 = ' + str(Cell1) + '\n')

      Cell2 = float(dcmp(10, 2, stream))
#     print('Cell2 = ' + str(Cell2) + '\n')

      Cell3 = float(dcmp(12, 2, stream))
#     print('Cell3 = ' + str(Cell3) + '\n')

      Cell4 = float(dcmp(14, 2, stream))

#     print('Cell4 = ' + str(Cell4) + '\n')

      Cell5 = float(dcmp(16, 2, stream))
#     print('Cell5 = ' + str(Cell5) + '\n')

      Cell6 = float(dcmp(18, 2, stream))
#     print('Cell6 = ' + str(Cell6) + '\n')

      Cell7 = float(dcmp(20, 2, stream))
#     print('Cell7 = ' + str(Cell7) + '\n')

      Cell8 = float(dcmp(22, 2, stream))
#     print('Cell8 = ' + str(Cell8) + '\n')
```

Figure 43. Python, finding SOC in the stream (Niskala 2022)

```
    # N.B. the Bat + and - sign at [28] is not compressed
      sign = stream[28];

      Batt_current = float(dcmp(29, 3, stream))
#      print('Battery current = ' + str(Batt_current) + '\n')

      PV1 = float(dcmp(32, 3, stream))
#      print('PV1 current = ' + str(PV1) + '\n')

      PV2 = float(dcmp(35, 3, stream))
#     print('PV2 current = ' + str(PV2) + '\n')
```

Figure 44. Python, finding battery current in the stream (Niskala 2022)

In the next part of the Python script the calculations are performed. Also, if the script is run manually from the command line, the read values are printed on the screen. A few matters explained related the calculation part of the script: The SBMS0 does not log directly the voltage of the battery bank, and therefore it is calculated as a sum of individual cells and divided by 1000 since the values is get as millivolts. This is highlighted in Figure 45.

```
# calculations
      Battery_SOC = int(SOC)
      print("Battery SOC = " + str(Battery_SOC) + "%")
      Battery_voltage = ((Cell1 +  Cell2 + Cell3 + Cell4 + Cell5 + Cell6 + Cell7 + Cell8) / 1000)
     # Battery_voltage = round(Battery_voltage, 2)
      print('Battery voltage = ' + str(Battery_voltage) + 'V')

      PV1_curr = (PV1 / 1000)
      PV1_current = round(PV1_curr, 3)
      print("PV1 current = " + str(PV1_current) + "A")
```

Figure 45. Python, calculations part 1 (Niskala 2022)

SBMS0 also doesn't log the power value either, so since I wanted it to be logged, the script calculates it by multiplying the instantaneous current by the battery voltage which was calculated in above. The power calculation is highlighted in Figure 46.

```
Load_curr = (Battery_curr - (PV1_current + PV2_current))
#Load_curr = ((PV1_current + PV2_current) - Battery_curr))
Load_current = round(Load_curr, 3)
print("Load current = " + str(Load_current) + "A")

Solar_power = (PV1_current + PV2_current) * Battery_voltage
Solar_power = round(Solar_power, 3)
print("Solar power = " + str(Solar_power) + "W")

Load_power = Load_current * round(Battery_voltage, 2)
Load_power = round(Load_power, 3)
print("Load power = " + str(Load_power) + "W" + "\n")

Cell_1 = (Cell1 / 1000)
print("Cell1 voltage = " + str(Cell_1) + "V") #added 20210403

Cell_2 = (Cell2 / 1000)
print("Cell2 voltage = " + str(Cell_2) + "V") #added 20210403

Cell_3 = (Cell3 / 1000)
print("Cell3 voltage = " + str(Cell_3) + "V") #added 20210403

Cell_4 = (Cell4 / 1000)
print("Cell4 voltage = " + str(Cell_4) + "V") #added 20210403

Cell_5 = (Cell5 / 1000)
print("Cell5 voltage = " + str(Cell_5) + "V") #added 20210403

Cell_6 = (Cell6 / 1000)
print("Cell6 voltage = " + str(Cell_6) + "V") #added 20210403

Cell_7 = (Cell7 / 1000)
print("Cell7 voltage = " + str(Cell_7) + "V") #added 20210403

Cell_8 = (Cell8 / 1000)
print("Cell8 voltage = " + str(Cell_8) + "V" + "\n") #added 20210403
```

Figure 46. Python, calculations part 2 (Niskala 2022)

In Figure 47 can be seen the end of the script, where in section 1 the csv file is named, in section 2 the fields / headers are written at the beginning of the csv file, in section 3 the logged values are written to the daily csv file and in section 4 the logged values are written to the temporary csv file. Sorry, but this figure had to be shortened to fit on the page and make it more readable.

```
#putting thigs to csv-file
      1) filename = time.strftime("%Y%m%d")
         timestamp = time.strftime("%x %H:%M")
      2) fields = "timestamp","SOC","Batt Voltage","PV1 Current","PV2 Current","Batt Current","Load Cu
         with open(filename + "_SBMS0" + ".csv", "a") as logfile:
           writer = csv.writer(logfile)
      3)   writer.writerow([timestamp, Battery_SOC, Battery_voltage, PV1_current, PV2_current, Battery_
         with open("SBMS0.csv", "w") as tempfile:
           writer = csv.writer(tempfile)
      4)   writer.writerow(fields) #writing the fields 20200909
           writer.writerow([timestamp, Battery_SOC, Battery_voltage, PV1_current, PV2_current, Battery_
       else:
         print("--> Something went wrong!!!")
ser.close()
```

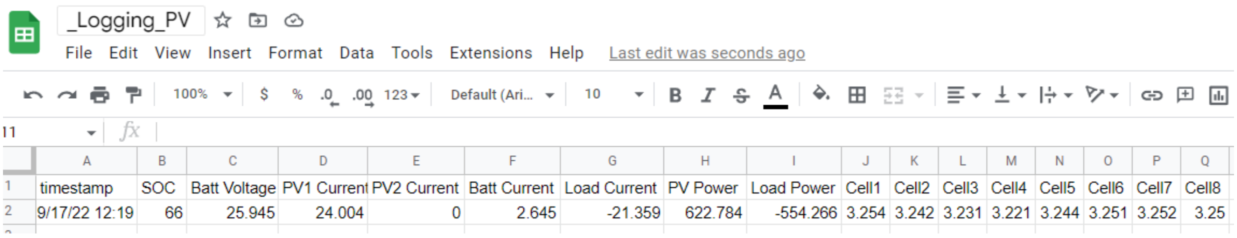
Figure 47. Python, csv related operation (Niskala 2022)

The last thing to mention about the python script, is the google sheets integration. In earlier figures I was describing the python script and there was a temporary csv file mentioned. This file is for storing the values every time the values is stored in daily csv file as well. The difference is that the daily csv is storing new row every minute, but the temporary csv file stores only one row and it is overwritten every minute. There is yet another script which read the data from that temporary csv file and upload the data into the google sheets. This way I get some assumption about the electricity production when I'm not at home by entering Google Sheets. The Google Sheets related script is shown in Figure 48. Note that the things related to my personal Google ID are overlined in the picture.

```
#!/usr/bin/env python

import gspread
from oauth2client.service_account import ServiceAccountCredentials

scope = ["https://spreadsheets.google.com/feeds", 'https://www.googleapis.com/auth/spreadsheets',
         "https://www.googleapis.com/auth/drive.file", "https://www.googleapis.com/auth/drive"]

credentials = ServiceAccountCredentials.from_json_keyfile_name([redacted], scope)
client = gspread.authorize(credentials)

spreadsheet = client.open('Logging_PV')

with open('SBMS0.csv', 'r') as file_obj:
    content = file_obj.read()
    client.import_csv(spreadsheet.id, data=content)
```

Figure 48. Google sheets integration (Niskala 2022)

How the values are shown in the Google Sheets can be seen in Figure 49.



timestamp	SOC	Batt Voltage	PV1 Current	PV2 Current	Batt Current	Load Current	PV Power	Load Power	Cell1	Cell2	Cell3	Cell4	Cell5	Cell6	Cell7	Cell8
9/17/22 12:19	66	25.945	24.004	0	2.645	-21.359	622.784	-554.266	3.254	3.242	3.231	3.221	3.244	3.251	3.252	3.25

Figure 49. Values in the Google Sheets (Niskala 2022)

The system is controlled and measured by the *SBMS0*. The PV-system include two current shunts for measuring: one for energy flow from panels, and one for energy flow going out from the battery bank. In Figure 50 you can see the principle of our whole system, which can also be seen in appendix 5.

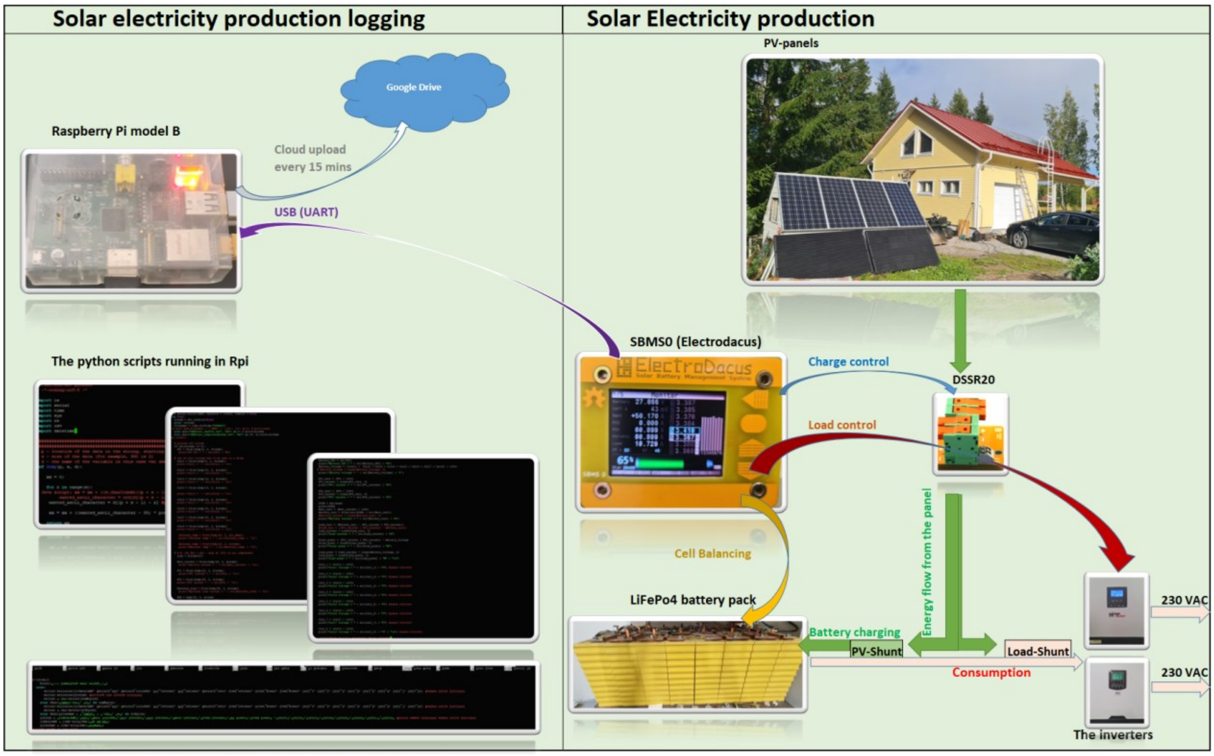


Figure 50. Principle diagram of the system (Niskala 2022)

3.6.1 The logging system output

My script output csv-file format in which there are eventually 17 cells in a row when imported to excel. There are: *timestamp*, *SOC*, *Battery voltage*, *PV-*, *battery-* and *Load currents*, *PV power*, *Load power* as well as individual *cell voltages*. *Battery voltage*, *Load current*, *PV power* and *Load power* are calculated values by the script.

Timestamp logging is performed by Raspberry Pi, it does not come from SBMS's internal clock. It just stores the current time in desirable format. The format is DD/MM/YYYY hh:mm. *SOC* is for State Of Charge, *Battery Voltage* is shown in volts, *PV1 current* in amperes, *PV2* is not in use. *Battery current* tells current flowing in/out from the battery, so it can be negative or positive. When it is positive, it means that the load is smaller than electricity production. *Load current* is calculated from PV1 and battery current. Then there are calculated PV power and Load power. In calculation of PV power there is Battery Voltage and PV current included in the formula, which is: *Battery voltage * PV1 current*. Load power formula is *Battery voltage * Load current*. An example of the file is presented below in Table 7 and can be found in Appendix 6 as well.

Table 7. View from an imported csv (Niskala 2022)

Date	SOC	Batt Voltage	PV1 curr	PV2 curr	Batt curr	Load curr	PV power	Load power	Cell1	Cell 2	Cell 3	Cell 4	Cell5	Cell 6	Cell 7	Cell 8
25/09/2022 11:59	63	26.551	43.785	0	25.538	-18.247	**1162.536**	**-484.458**	3.278	3.348	3.317	3.317	3.357	3.299	3.33	3.305
25/09/2022 12:00	63	26.667	47.031	0	25.172	-21.859	**1254.176**	**-582.98**	3.337	3.331	3.323	3.326	3.333	3.339	3.338	3.34
25/09/2022 12:01	63	26.654	47.022	0	28.339	-18.683	**1253.324**	**-497.902**	3.336	3.328	3.321	3.325	3.331	3.338	3.336	3.339
25/09/2022 12:02	63	26.674	43.013	0	23.667	-19.346	**1147.329**	**-515.958**	3.338	3.332	3.324	3.327	3.334	3.34	3.339	3.34
25/09/2022 12:03	64	26.708	46.484	0	32.678	-13.806	**1241.495**	**-368.758**	3.265	3.39	3.339	3.388	3.302	3.354	3.351	3.319
25/09/2022 12:04	64	26.765	46.877	0	35.316	-11.561	**1254.663**	**-309.488**	3.272	3.398	3.345	3.351	3.396	3.32	3.359	3.324
25/09/2022 12:05	64	26.626	48.748	0	37.779	-10.969	**1297.964**	**-292.104**	3.256	3.379	3.328	3.33	3.379	3.302	3.343	3.309
25/09/2022 12:06	64	26.885	42.138	0	30.978	-11.16	**1132.88**	**-300.092**	3.364	3.359	3.35	3.355	3.36	3.367	3.364	3.366
25/09/2022 12:07	64	26.638	46.952	0	30.764	-16.188	**1250.707**	**-431.248**	3.335	3.326	3.321	3.322	3.329	3.334	3.334	3.337
25/09/2022 12:08	64	26.707	43.781	0	23.184	-20.597	**1169.259**	**-550.146**	3.342	3.336	3.328	3.331	3.337	3.344	3.343	3.346
25/09/2022 12:09	64	26.696	36.601	0	17.139	-19.462	**977.1**	**-519.635**	3.326	3.346	3.33	3.332	3.346	3.336	3.342	3.338
25/09/2022 12:10	64	26.608	46.673	0	27.61	-19.063	**1241.875**	**-507.266**	3.253	3.378	3.327	3.329	3.376	3.3	3.34	3.305
25/09/2022 12:11	65	26.752	44.618	0	31.614	-13.004	**1193.621**	**-347.857**	3.272	3.397	3.344	3.395	3.308	3.357	3.357	3.322
25/09/2022 12:12	65	26.749	46.073	0	35.365	-10.708	**1232.407**	**-286.439**	3.27	3.395	3.344	3.349	3.394	3.318	3.357	3.322
25/09/2022 12:13	65	26.894	46.037	0	35.312	-10.725	**1238.119**	**-288.395**	3.364	3.361	3.352	3.356	3.362	3.368	3.365	3.366
25/09/2022 12:14	65	26.91	46.641	0	36.204	-10.437	**1255.109**	**-280.86**	3.367	3.363	3.354	3.358	3.363	3.37	3.367	3.368
25/09/2022 12:15	65	26.77	47.01	0	31.055	-15.955	**1258.458**	**-427.115**	3.35	3.345	3.337	3.341	3.345	3.351	3.35	3.351
25/09/2022 12:16	65	26.624	44.953	0	22.982	-21.971	**1196.829**	**-584.868**	3.254	3.379	3.331	3.333	3.379	3.301	3.341	3.306
25/09/2022 12:17	65	26.614	40.973	0	21.474	-19.499	**1090.455**	**-518.868**	3.253	3.378	3.329	3.331	3.377	3.3	3.34	3.306
25/09/2022 12:18	65	26.568	39.39	0	20.334	-19.056	**1046.514**	**-506.318**	3.248	3.372	3.324	3.326	3.37	3.294	3.334	3.3
25/09/2022 12:19	65	26.741	38.713	0	22.367	-16.346	**1035.224**	**-437.092**	3.331	3.351	3.336	3.339	3.353	3.341	3.347	3.343
25/09/2022 12:20	66	26.696	34.261	0	23.883	-10.378	**914.632**	**-277.093**	3.341	3.335	3.329	3.331	3.337	3.341	3.341	3.341
25/09/2022 12:21	66	26.706	31.694	0	21.416	-10.278	**846.42**	**-274.525**	3.343	3.336	3.329	3.332	3.338	3.343	3.341	3.344
25/09/2022 12:22	66	26.647	31.696	0	18.769	-12.927	**844.603**	**-344.505**	3.336	3.33	3.324	3.327	3.33	3.332	3.334	3.334

Also, I checked my own calculations as well to be sure that energy production calculations are accurate enough. The comparison between production values from SBMS0's display and logged data from own monitoring system. Below you will find some checks related to calculations. Figure 51 and 52 are showing the pictures taken from SBMS0's display in 25.9.2022.

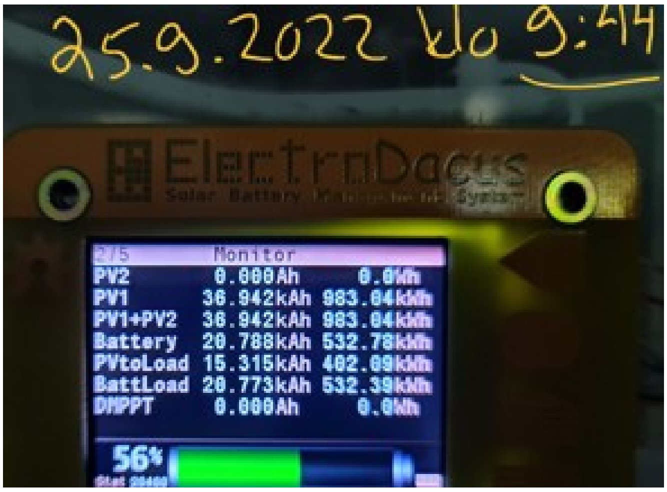


Figure 51. SBMS0 values 25.9.2022 9:44 (Niskala 2022)

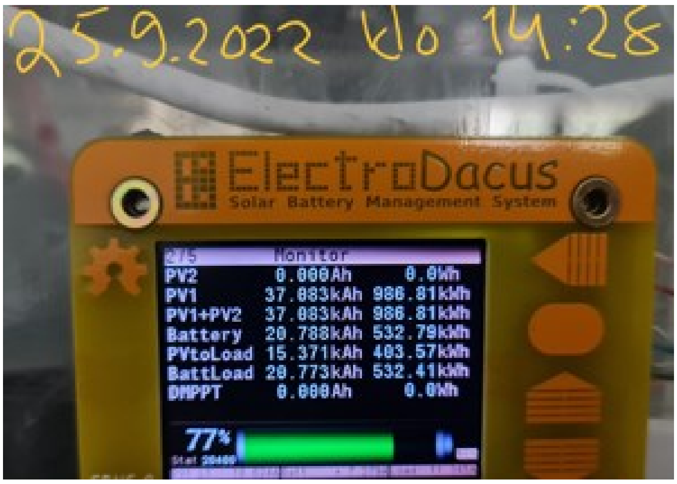


Figure 52. SBMS0 values 25.9.2022 14:28 (Niskala 2022)

Based to pictures taken, the production, during that time period (9:44...14:28) was:
983,04 kWh – 986,81 kWh = 3,77 kWh.
During that time period there were 283 rows logged in one minute interval, which means overall 4,71 logged hours. The average power calculated from that time period was 0,79 kW. Multiplying the average power value by logged hours we get → 3,73 kWh, which is relatevely close the value calculated by the *SBMS0*. You can find this check also in the last page of appendix 6.

4 OBJECTIVES AND RESULTS

Main objective was to design and build a photovoltaic system, which'd hopefully produce primarily most of the electricity needed for the E-REV for certain part of the year, and not to forget the LiFePo4 batteries and aspects related to *BMS*. From the perspective of research, the potential of solar electricity was considered by researching data gathered from the old PV-system and evaluating & calculating the data gathered from the car itself.

The size of the new system was determined by using earlier production data from four-panel photovoltaic system. It is good to keep in mind that the old system was not located in optimal location in the premises regarding to solar radiation. The old panels are practically installed at ground level next to the old spruce fence, which even in the summer affects the production of the solar panel system when the sun shines from the west. The new panels are located on the roof, so when the sun shines from the west, the spruce fence does not prevent the solar radiation from entering towards the panel field and therefore the irradiation reaches the panels of the new system for a longer time in the day than the panels of the old system. Also, the installation angle of the old panels is approx. 40 degrees, and the angle of the new panels located on the roof of the garage is approx. 30 degrees. In optimal environmental conditions the difference "in power" between these two installation angles on a yearly basis is below 1 %, as shown in Figure 55 on the page 51. Based on the above, i.e., that the spruce fence does not shade the new panels, and the installation angle is as mentioned, the new panels should receive relatively more irradiation during the annual review period than the panels according to the old installation.

The picture in the front page shows how close to the spruce fence the old panels are. Also, information can be seen in Figure 53 below.

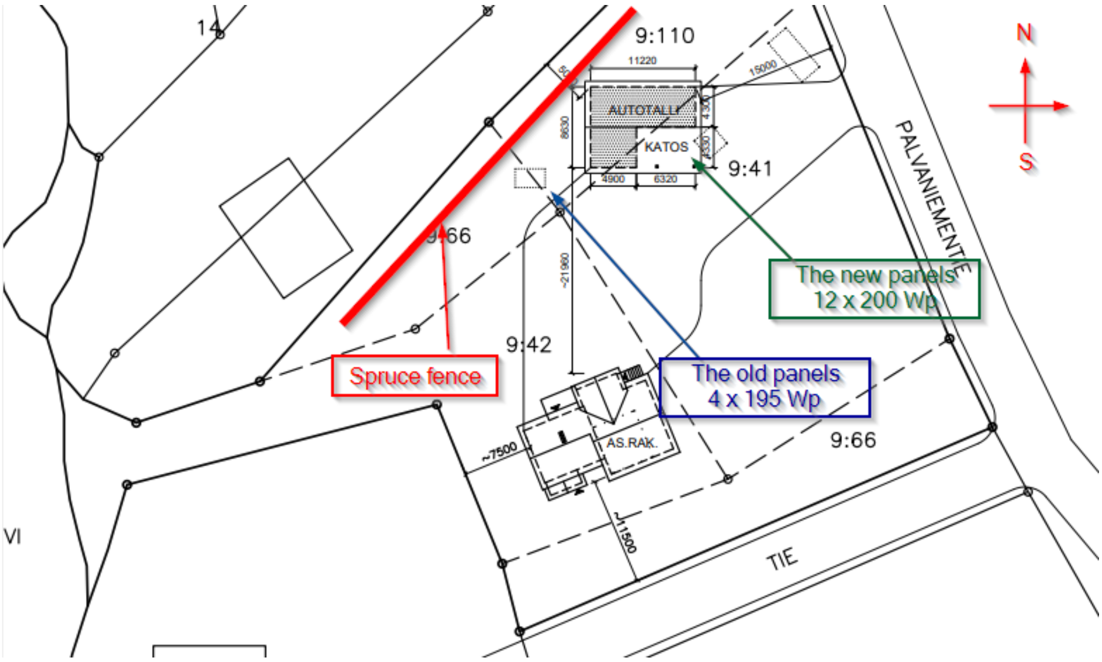


Figure 53. Position drawing with comments (Niskala 2022)

For most people there is not much to influence when talking about installation angle of the solar panels. In conventional private properties, the panels are most installed on the roof, so the angle cannot be affected, because in many locations the building/planning regulations oblige to install the panels parallel to the roof. Also, in the roof installations, you cannot do much about the installation direction either. However, it is always good to gain knowledge / familiarize yourself related, what kind of installation direction and angle is said to be annually the best. In Finland, the optimal angle of the solar panels is 40 – 45 ° (Finnwind, 2017). Figure 54 shows the effects of panel orientation on electricity production on an annual basis.

Installation direction	Production (%) in Helsinki
East	75.5%
Southeast	92.5%
South	100.0%
Southwest	93.9%
West	77.7%

Figure 54. Installation direction and production in Helsinki (Finnwind, 2017)

And Figure 55 is presenting the influences of the installation angle on production.

Installation angle (°)	Production (%) in Helsinki
10	90.0%
20	95.7%
30	99.1%
40	100.0%
50	98.4%
60	94.4%

Figure 55. Installation angle and production in Helsinki (Finnwind, 2017)

4.1 Battery performance

Within the project I realized that if the constant current flowing from the batteries to the load is larger, the less energy I get out of them. The higher the continuous current is taken from the batteries, the lower the overall amount of energy obtained from the batteries is in practice. It's challenging to put into words, but when the continuous current is high, the differences between the individual battery cells start to show practically earlier than if the batteries were loaded with a lower current.

This is characteristic of batteries, but this did not come to my mind when I was working things out on paper. A little perspective on how large currents we are talking about: If the charging current of the car is 6 A / 230 VAC, the current flow in DC-side of the system is a bit more than 60 A. If you choose to charge your car with 10 A / 230 VAC, the current flow in DC-side of the system is over 100 A!

When taking more about this amount of current from the batteries, like said above, the separate cells will start to show their weaknesses and mutual voltage balance of the cells of the battery pack begins to suffer, which can be seen as an increasing delta V. Delta V is the voltage difference between the weakest and the healthiest cell. Also, when the differences between individual voltages of the cells are getting larger, it affects the entire battery banks voltage. In our case, the inverter is the one doing actions related primarily, but if the inverter does not switch the supply from battery to national electricity grid in event of battery voltage drop for some reason, the SBMS0 switches off the inverters completely.

The SBMS0 turn the inverter off, if the balance of two cells exceeds 150 mV. It has not happened that the delta V was over the limits in daily action, but I cannot take the full capacity from the batteries either while charging my car, because the voltage of the entire battery bank drops below the set level.
When SOC is approaching 50 %, it basically means that energy in the battery is running out. This led to a fact that in E-REV charging use, I do not have 400Ah battery in our system in practice. It is

more like 200 Ah battery. But if I load the batteries by using more decent amount of current, the capacity should be larger.

At some point in life, it is necessary to measure the actual capacity of the battery pack, when, for example, it is loaded with a stable current of 10 or 20 amperes.

4.2 The challenges

In this project it was meant to gather more real-life data from the panels after installation to see how the system performed and how the electricity was enough to charge the car. The data was gathered and examined. I was very surprised that the old four 195 Wp panels produced more electricity on a sunny day than the six new panels combined! Even though the old ones had been in use for 6-7 years and one new panel was, according to the specs, 5 Wp more efficient than one old one. In addition, the company through which I got the new panels had stopped operating. There I was, reaching directly panel manufacturers after sales department, which I finally got in touch with. It took over six months to get final answer from manufacturer. Within these six months I gathered serial numbers, wrote a dozen emails, measured panels electricity production and surface temperatures to deliver those to manufacturer. After all, it took so long to pull this off because the manufacturer couldn't find any production reports on the panels at first. When they finally found, they directly announced that: "We are happy to announce that you will receive new panels". Well, in that point the process was not over yet. After another couple of months, the manufacturer informed that the panels I bought were not available anymore. So, I had to go through their product portfolio and choose new panels. I finally found the closest suitable panel from their selection, and now I already have the panels waiting for installation. Below you can see example of the measurements what I did and delivered to manufacturer. In Table 8 can be seen the current measurements of defective Luxor panels. There can also be seen the surface temperature measured from the panel number #8

Table 8. Luxor, the new panels measurements (Niskala 2022)

	Measurements Luxor (A)	
panel nro	13.7.2021 cl 10:15	13.7.2021 cl 11:10
#1	0,99	2,45
#2	1,87	3,27
#3	1,04	1,15
#4	1,25	2,48
#5	1,46	1,68
#6	0,93	1,86
#7	1,01	1,47
#8	1,06	1,28
#9	0,77	0,92
#10	0,71	0,97
#11	2,54	2,42
#12	0,74	1,01
	temp, panel #8 = 42 °C	temp, panel #8 = 59 °C

And in Table 9 can be seen comparison measurements from old ETSolar panels, and surface temperature measured form the panel nro #2.

Table 9. ETSolar, the old panels measurements (Niskala 2022)

	Measurements EtSolar (A)	
panel nro	13.7.2021 cl 10:18	13.7.2021 cl 11:12
#1	3,4	4,62
#2	3,36	4,68
#3	3,37	4,61
#4	3,41	4,58
	temp, panel #2 = 42 °C	temp, panel #2 = 59 °C

As you see, the best Luxor panel, nro #2 in Table 8 produced approx. 70 %, and the worst, nro #9 in Table 9, below 20% of the current compared to ETSolar panel nro #2 in Table 8.

Also, you can see in the tables how the surface temperature has been increased after approx. 40 minutes operation in direct sunlight. The increasement of surface temperature is normal in operation, thou.

Figure 56 shows what I have analyzed to be internal faults in the panel. The picture was taken in the middle of February right after the snow was cleaned from the panels. There are four "spots" on the panel's cells. The spots indicate that the cells generate heat in a spot-like manner, which is presumably due to bad connections inside the cells. If the panel were in good condition, no dot-like points should be visible, and the heating of the cell due to current flow would be distributed more evenly on the surface of the cell.

Figure 56. Defective panels in action (Niskala 2022)

The challenge is, that those panels what I bought first, are integrated into the roof. Now once I find time to uninstall the panels, I need to modify the structure of the roof in order to get new panels to fit into the roof structure. The physical dimensions (w x l) of the panels I bought first is 808 mm x 1580 mm. The new 310 Wp panels are: 1000 mm x 1665 mm each!
It can be done but require designing and time.

I did not get a refund because I must disassemble the installation of the panels and change the roof structure, since the company, I bought the panels from no longer exists. Also, at the end of the long process, I didn't have enough energy to start clarifying and demanding a refund from the panel manufacturer, with whom I was directly in contact as an end user. However, for this information, I get to keep the old panels myself, so in the future it might be possible for me to build a different kind of system by using the panels, even they do not produce electricity as much they should.

Also, one of the challenges of the project was a thunderstorm that broke the SBMS0. Fortunately, I got quick help with this from the *Electrodacus* representative, who helped to locate the failed component, which I ordered and replaced with a new one. The component was a tiny smd ic, and I had to dig out an old and small smd soldering iron from naphthalene, with which I performed corrective measures. And yet another challenge within this project was demanding and hectic working life, and garage building project. Last year was a true challenge, and eventually I had really limited time to promote this project, but this year made it possible to gather all things into this report.

4.3 The components and installations of the new system

The system was built in a way that by using electricity outlets electricity was available regardless of whether it there was energy in the batteries or not. This obtained by using hybrid inverters which were able to switch to electricity grid on-the-fly. In my opinion the hybrid word means two things in the device. One is that hybrid-inverter is a device which can be used to charge the batteries as well, if lead acid batteries would be used. The second is that the inverter can take energy from which it produces alternating current from another source in addition to the DC battery, in this case the national grid. In my system the DC battery is configured to be inverter's primary source. The inverter produces alternating current from the energy it receives from the battery until the lower limit of the battery voltage set on the inverter is reached. And when it is reached, the inverter switches "on the fly" to the secondary source, i.e., the national grid. Network switching takes place in about 10 - 20 milliseconds (MPPSolar, 2018). The second energy source of the hybrid inverter can also be, for example, an aggregate.

Since the garage was built at the same time as this project, I modified the new system into one that also serves the other electrification loads of the garage, as well as certain electrical groups in the house. The equipment in the garage that uses solar electricity includes, in addition to the car charging unit, a motorized garage door, all the lights, a heating cable for rainwater well, and an air heat pump for heating. I rather not to wrote much in here since in appendix 4, shows the main diagram of the system. All I'm saying is that right now, sitting in my study in the basement of the house, my computers and peripherals are running just fine with electricity from the roof of the garage!

As I work with electricity and instrumentation nowadays, I know a bit related to electrical installations, groundings, cable calculations etc. All installations were made according to standards. The cables were chosen with the idea that sometimes the power requirement is higher. For example, the cable laid between the garage and the house is a 10 mm2 Cu cable, although the real need in current configuration for which produce at maximum 3000 W one phase AC electricity would be a 2.5 mm^2 cable.

4.4 Estimation of costs

When I bring up the costs in a small sum up below, I'm not including anything other than the cost of purchasing the equipment, since I'm such a character who likes to think, wonder and create things on free time as well. Indicative prices are presented in table 10.

Table 10. The prices of the system (Niskala 2020)

The item	**The price (€)**
Solar panels	2400
SBMS0	230
Hybrid inverter	600
Cables, fuses switches, etc	800
Sum	**4030**

4.5 Power generation of the new system

Since we had some quality problems with panels, described in chapter 4.2, the system did not perform last year that good comparing to this year. When I got the replacement panels delivered to me, I installed two of them into the system. The panels are 310 Wp panels as I mentioned in chapter 4.2 as well. The panels can also be seen in the cover photo, in the foreground.

As a comparison, the electricity production of last and this year are shown in table 11.

Table 11. The electricity production (Niskala 2022)

2021	
	Production (kWh)
January	0.57
February	4.74
March	44.94
April	128.99
May	157.60
June	186.01
July	174.41
August	111.24
September	66.28
October	
November	
December	
Sum	**874.78**

2022	
	Production (kWh)
January	0.09
February	14.70
March	125.47
April	165.39
May	218.25
June	206.95
July	212.99
August	211.85
September	112.08
October	43.50
November	
December	
Sum	**1267.75**

Those two temporarily installed new panels gave a boost to the electricity production comparing to last year. However, this is not the whole truth since the solar radiation were not monitored in my studies and summers can be quite different in a perspective of radiation. If we look further this year production we can calculate how the produced amount of electricity meets the calculation related the size of the system.

Previously I calculated that we would need four times bigger system to harness full month's energy in 21 working days in a month. So, if we calculate the average DC electricity production in a month between March to August, which was a time period I used in previous calculations, we get it by placing values from Table 11 to equation 18.

$$DC\ electricity = \frac{(125{,}47+165{,}39+218{,}25+206{,}95+212{,}99+211{,}85)kWh}{6\ month} = 190{,}15\ \text{kWh/month} \quad (18)$$

Then we divide that value by 21 working days in a month in equation 19.

$$DC\ electricity = \frac{195{,}15\ kWh}{21\ d} = 9{,}055\ kWh/\text{d} \quad (19)$$

You may recall that I used 0,95 as inverters effiency, which was not calculated value. This time we will use the average value of inverter efficiency factor shown previously in Table 6. This is presented in equation 20.

$$AC\ electricity = 9{,}055\ kWh/\text{d} * 0{,}886 = 8{,}023\ \text{kWh/d} \quad (20)$$

And in addition to this we need to consider car charging efficiency as well to get the amount of electricity transferred to E-REV's battery. This is shown in equation 21.

$$AC\ charging\ electricity = 8{,}023\ kWh/\text{d} * 0{,}84 = 6{,}739\ \text{kWh/d} \quad (21)$$

Just to remind, previously I calculated the AC electricity needed which was 9,168 kWh/day, which was the E-REV's consumption considered with electricity transformation losses, and this was shown in equation 7.

So in this point the electricity produced is not enough, but I assume that it will be enough when I get all the replacement panels installed. Based on logged data the system produced this year DC electricity 9,055 kWh/d shown in Equation 20, AC electricity 8,023 kWh/d shown in Equation 21, and theoritacally 6,739 kWh/d could be transferred into E-REV.

The car's consumption with electricity transformation losses was, according the Equation 7, 9,168 kWh/d, we can then calculate the percentage value comparing AC electricity needed per day and how much the new system is able to charge our E-REV. This is shown in Equation 22.

$$= \frac{6{,}739\ kWh/d}{9{,}168\ kWh/d} * 100 = 73{,}5\ \% \quad (22)$$

In other words, above calculated value tells the percentage value of how much theoretically we got electricity from the solar electricity system if all of it would have used to charge the car.

This means also, that in one working day the car would go with the electricity taken from wall plug like presented on Equation 23.

$$= 5{,}235 \frac{km}{kWh} * 6{,}739 \frac{kWh}{d} = 35{,}279 km/d \quad (23)$$

As a reminder 5,235 kWh was the inverse value for 0,191 kWh/km, which was presented in Equation 4 in the chapter 3.4.1 Car efficiency.

The result of the calculation, 35,279 km, is based on a system with 4 pcs of old 195 Wp panels, 12 pcs of underpowered 200 Wp panels, which turned out to be defective, and 2 pcs of 310 Wp panels received in place of the defective ones. The real sufficiency of electricity to charge the car will only be seen when all the new 310 Wp panels can be harnessed to replace the defective ones.

As a real world in the perspective the battery size / condition does not allow to store the amount of electricity needed to harness it in 21 working days only. In average the energy produced in a month was 191.15 kWh, which means 191,15 kWh / 30 days = 6,37 kWh/day. Therefore, the amount of electricity to be stored during the weekend would be 12,74 kWh, while the battery can store approximately 6-7 kWh in its current state. Doubling the battery capacity would therefore help to get closer to the calculated amount of energy.

This project started from an idea to create a system to produce electricity primarily for E-REV. As years went by, the design and construction project of the garage came into play, so it was necessary to develop this project a little more along the way by considering other consumers as well. In this work the dimensioning, modification and production readings of the system were examined from the perspective of car charging, although solar electricity can be also used in other consumption areas of the property. In reality, it is possible for me to still use the electricity obtained from the panels to charge the car only, but in practice I choose according to the situation where the electricity is needed at certain time. So I can choose whether to feed it into the car or distribute it to the house, via another inverter, or even both. If solar electricity were to be used only to charge the *E-REV*, based on the calculations, it would cover (35,284 km / 48 km) * 100 = 73,5 % of the daily driving.

And because there were challenges in the form of defective panels, it was not possible for me to get practical measurement results on how the electricity produced by the panels is enough to charge the car in the long run. Regarding these, I will be wiser at the point when the replacement panels have been installed on the roof and the electricity produced by them has been used from early spring to late autumn.

5 APPENDICES

Appendix 1 RRD Graphs from old system

Appendix 2 Data and calculations

Appendix 3 Car Efficiency

Appendix 4 Main diagram of the new electricity system

Appendix 5 Principal diagram of the system

Appendix 6 An example csv and calculation check

Appendix 7 Summation tables

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