

Commissioning and Operation of SCADA Systems in Photovoltaic Power Plants

Axel Eskman

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Författare: Axel Eskman

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Handledare: Hans Lindén (Yrkeshögskolan Novia)

Aapo Lindqvist (Solnet Finland Oy)

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Abstrakt

Detta examensarbete presenterar ett systematiskt tillvägagångssätt för driftsättning och användning av Meteocontrol VCOM cloud SCADA systemet i Fotovoltaiska (PV) kraftverk. Arbetet kommer att fokusera på två huvudområden: driftsättning och användning. Det är viktigt att båda områden har ett klart och metodiskt tillvägagångssätt för genomförandet. Det kommer att se till att alla framtida systemen är liknande i funktion och med detta säkerställa en effektiv process.

Examensarbetet gjordes för Solnet Finland Oy som är ett företag som specialiserat i smarta solkraftverk. Arbetet använder en iterativ process. Först presenteras en teoretisk metod sedan testas och utvärderas den. I utvärdering har användarvänlighet och prestanda största vikten. Efter utvärdering anpassas den första metoden för att förbättra processen. Denna iterativa process kan göras på nytt för att optimera metoden vidare.

Målen uppnåddes med att använda redan etablerade processer och tillvägagångssätt från andra områden inom företaget och anpassa dem för detta användningsändamål. För att uppnå det sista funktionella och effektiva systemet krävde insättande in i de olika aspekter av PV-kraftverk samt diverse industriella kommunikationsprotokoll.

Språk: engelska

Nyckelord: fotovoltaiska kraftverk, solkraftverk, SCADA, övervakning av kraftverk

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Author: Axel Eskman

Degree Programme: Electrical Engineering and Automation

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Supervisor(s): Hans Lindén (Novia University of Applied Sciences)

Aapo Lindqvist (Solnet Finland Oy)

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Abstract

This thesis presents a systematic approach on how to commission and operate the Meteocontrol VCOM cloud SCADA system in photovoltaic (PV) power plants. This work will focus on two main areas, commissioning and operation. It is vital that both areas have a clear and methodical approach to implementation as it will ensure that all the future systems are identical in nature and will thus save resources and improve efficiency.

This work is done for Solnet Finland Oy which is an international EPC company that specializes in smart solar solutions. This thesis utilizes an iterative process. First, an initial theoretical approach is presented, which is then tested and evaluated. In this evaluation, the ease of use/implementation and overall system performance will bear the main weight. After evaluation, the initial approach is adjusted to improve the process. This iterative process can also be repeated afterwards to further optimize the approach.

These goals were achieved by utilizing already established company processes and workflows from different fields and adapting them to fit this use case. Research into the various aspects of PV power plants and industry standard communication protocols was required to achieve this final functional and performant system.

Language: English

Key words: photovoltaic power plant, solar power plants, SCADA, power plant monitoring

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1 Introduction

This work will focus on the technical aspects of the commissioning and operation of a SCADA system for photovoltaic power plants. This SCADA system is implemented to follow customer requirements and to give redundancy to the existing monitoring solution. In this work, only SolarEdge inverters are used but other manufacturers' inverters should follow a similar procedure, as the communication interface has been standardized. In the end, a refined approach is presented, which can be further distilled into a clearer guide for all future Meteocontrol VCOM implementations. [1]

The importance of having a monitoring solution for PV systems is ever-increasing as sustainability goals increase and people demand more information. Implementing such a SCADA system is a great way to gather data and evaluate key performance indicators (KPIs).

This thesis is done for Solnet Finland Oy which is a company that specializes in smart solar solutions. The focus of this work will be on commercial power plants in the 100 - 1000 kW range as they are the most relevant to Solnet currently. By only focusing on power plants under 1MW a lot of additional work is avoided as power plants over 1MW belong to the B class of power plants which have a lot of additional requirements in both communications and testing. [2]

2 Solar energy technologies

In the umbrella term solar energy, there are a lot of different technologies and systems. This work is focused on photovoltaic systems but will discuss other types of solar power plants as well. PV systems are nowadays the most popular due to low cost, high efficiency and, market maturity. PV systems can be installed almost anywhere whereas, for example, power plants utilizing thermal radiation take up lots of space and have quite strict requirements in terms of the environment and geographical location. Which is why you do not really see them in more northern parts of the world.

2.1 Photovoltaic

Photovoltaic power plants utilize the photovoltaic effect. It is a physical phenomenon discovered by Edmond Becquerel in 1839. When sunlight or any light source with sufficient energy and of suitable wavelength hits the photovoltaic material, the energy is absorbed exciting electrons enough to knock them loose from their atoms. This creates a free electron and a corresponding electron-hole. This in itself is not useful as there is no potential created because the charges are not separated. For this effect to be useful you need to have a way to separate the charges from each other to create an electrical potential.

In modern photovoltaics, this is usually done with semiconductor materials, specifically P-N junctions. These P-N junctions as the name implies are a junction of P-type and N-type materials. The N or P in the name refers to whether the material has more electrons or electron holes. If a material has an excess of electrons, it is negatively charged and if a material has an excess of electron holes it is positively charged. If you then connect these two materials, there is an electric potential created between them, this fundamental electric potential can be used to separate the electrons from the electron holes. [3]

There are many different technologies that utilize the PV effect to generate electricity. The most common being thin film, monocrystalline, and polycrystalline. These different technologies all have their advantages and disadvantages, which will be discussed next.

2.1.1 Thin Film

Thin film is a technology that as the name suggests utilizes thin films of material instead of solid lab-grown silicon crystals. Thin film solar cells are the second most used technology after crystalline silicon. In thin film solar cells, a thin film of material, usually Cadmium Telluride (CdTe) is deposited onto a conductive glass sheet. The layer of CdTe only needs to be a few micrometers thick to absorb 90% of the photons as the material has a high absorption coefficient. This is where the name “thin film” comes from. CdTe solar cells have been in use since the 1970s but are not as popular as crystalline silicon technologies due to relatively low efficiencies, low lifespan, and the toxic nature of tellurium and its relative scarcity compared to silicon [4].

This technology does have one advantage over crystalline silicon. Due to its thin film structure, it is possible to make flexible solar cells. However, this is a relatively niche application and serves no purpose in large-scale PV systems. [5]

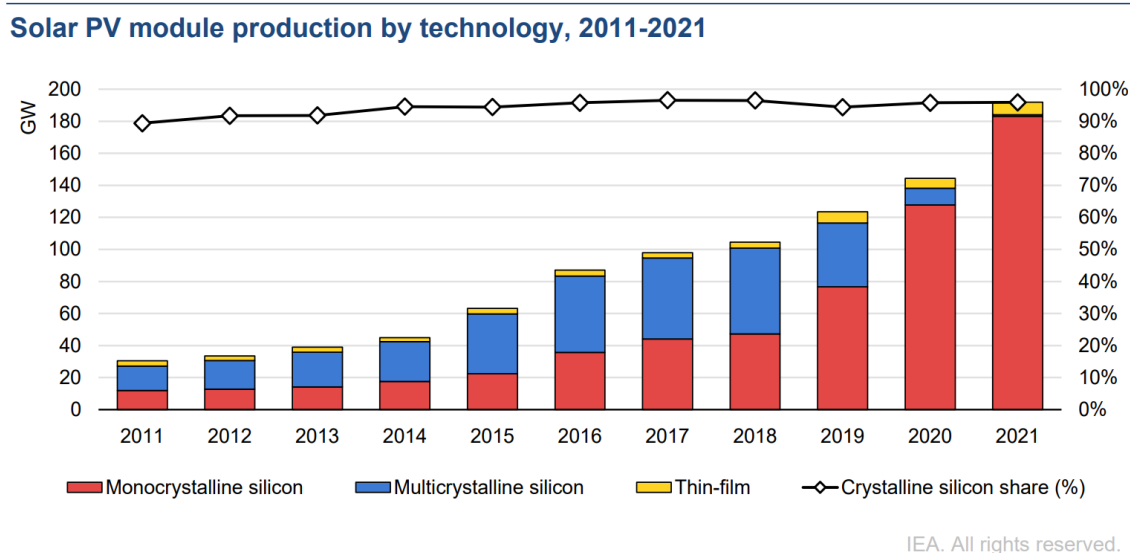
2.1.2 Crystalline silicon

Crystalline silicon solar cells as the name implies are made from crystalline silicon. There are two main types of crystalline silicon cells: monocrystalline and polycrystalline.

Monocrystalline solar cells are the most popular nowadays due to improvements in technology to get efficiency up and costs down. Monocrystalline solar cells can reach up to 24,8% efficiency in mass-produced products and at the lowest price per watt today [5] [6].

To get crystalline silicon the same methods of manufacturing are used as in the electronics semiconductor business. Silicon is not an optimal material choice for making solar cells. But it is currently dominating the solar cell market with over 95% of all solar cells sold being crystalline [7]. The reason for this is mainly that before the solar cell market, there was already a mature and efficient pipeline for manufacturing high-quality silicon wafers for the electronics industry.

Polycrystalline is the other main type of silicon cell. They were more popular years before when high-quality silicon wafers were more expensive. But now that the market has matured silicon wafers are relatively inexpensive. In Figure 1 you can see that in 2019. The polycrystalline market began to decline massively. And in two years it is almost completely gone. [7]



Source: IEA analysis based on BNEF (2022a), IEA PVPS, SPV Market Research, RTS Corporation and PV InfoLink.

Figure 1 Graph of PV module production from 2011-2021 [7]

Polycrystalline silicon cells are not made from a singular homogeneous crystal but instead are made from chunks of silicon melted together. This means that due to natural inconsistencies formed during the process, it is not as efficient as monocrystalline. [8]

Polycrystalline cells have also fallen out of favor in recent years as monocrystalline cell production has decreased in cost. In 2021 polycrystalline cells had under a 1% market share. This number is nowadays likely even lower. [7]

2.2 Thermal Solar Energy

Thermal solar energy is a broad definition. It encompasses systems that capture solar energy to heat water in residential buildings, and systems that concentrate sunlight from many hectares of mirrors onto a single point to heat molten salt to 1000 degrees Celsius.

In this chapter, the focus will be on large-scale so-called concentrating solar power plants (CSP). As there is no notable usage in the 100 - 1000 kW range. Most CSP plants lie in the 10-100 MW power range [9]. Large CSP plants utilize the oldest methods of creating electricity. Namely using heat, in this case from the sun to produce steam. Then using this steam to drive a steam turbine. This turbine is connected to an electrical generator which then generates electricity from the kinetic energy. The water is then cooled and sent back to be made into steam. Before solar panels got more efficient and their price dropped, this was a very good method to generate electricity in hot climates. As it uses proven technologies and used to have a lower cost than PV systems. [10]

Nowadays this has changed in favor of PV systems in most climates. There is still a case to be made in very hot climates, as solar cells become more inefficient as the cell temperature rises. And as they have a dark albedo this means that they heat a lot from sunlight. These hot climate locations are, however, usually in quite remote locations with little to no infrastructure and energy demand. Making large-scale CSP plants there is not optimal. [9]

There is one big upside with CSP though namely thermal energy storage. It is much easier to store thermal energy than it is to store electrical energy. To store thermal energy, you just need a big mass of material whereas in electrical energy you need to store the energy in batteries. [11]

2.3 Components in photovoltaic systems

2.3.1 Solar Panels

Solar panels, also called modules, are components that assemble large amounts of solar cells into a package that is robust and easy to handle. Most solar panels have 100 - 150 half-cut solar cells. These are wired in a combination of series and parallel to achieve desirable voltage and current characteristics. [12] - [13]

To compare different solar panels a few key metrics are used:

Peak power or Watt-peak (W_P): Is the maximum power the solar panel can produce in watts under standard testing conditions (STC). This is usually in the 400 – 600 Wp range nowadays.

Open circuit voltage (V_{oc}): This is the maximum voltage the solar panel can achieve under STC. As the name implies, this voltage does not apply if there is a load on the system. V_{oc} ranges from 38 - 53V depending on cell technology and topology. This metric is particularly important in traditional PV where modules are directly wired in series to the strings. In these cases, the V_{oc} increases additively for every additional module in the string.

Short circuit current (I_{sc}): Is the maximum current that can be achieved by shorting the solar panel under STC. This value typically ranges from 10 to 15 A depending on topologies and cell technology. This is also an important metric to consider, as a very high I_{sc} can result in high cable losses, and in optimized systems cause the optimizer to fail. In traditional PV the cabling must be dimensioned to withstand the I_{sc} .

One of the most important things to understand about solar panels is how the power changes according to the voltage. This relationship is described in the so-called P-V curve that is usually available in the manufacturer's datasheet. Below is a P-V curve of a Trina Solar solar panel.

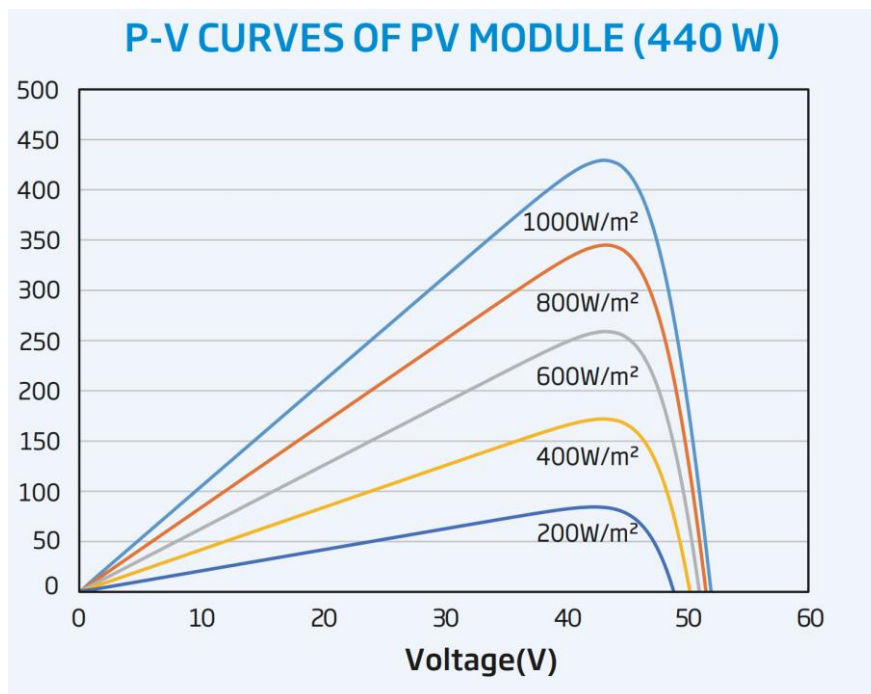


Figure 2 P-V curve of Trina TSM-440 solar panel [12]

In this graph you can see that power depends heavily on the voltage and this relationship changes as the irradiance changes.

Common mass production modules nowadays produce around 450Wp of power under standard test conditions (STC). In traditional PV systems, the cost of the power plant is mainly dictated by the cost of the solar panels and labor. This equation changes slightly in optimized systems, as power optimizers are quite expensive.

2.3.2 Inverters

Inverters are in essence quite simple, however in practice, they are quite complicated devices. In all simplicity, it is a device that takes in DC power and converts it into AC that can be supplied to the grid. Nowadays, however, grid-connected inverters have grown quite complicated due to regulations and optimizations. One of the most important jobs of inverters in traditional PV systems is to optimize the currents in the strings.

This is achieved using so-called Maximum Power Point Trackers or MPPTs. MPPTs are circuits that monitor the voltage and current of the strings and adjust the current to squeeze the maximum amount of power from the strings. This is needed as the maximum power point (MPP) of a given string will change during the day due to different temperatures, irradiances, and even partial shading of module arrays can have a big impact on the MPP.

In traditional systems inverters usually have several MPPTs to make the whole system more efficient. If there was only one MPPT and one of the strings was producing poorly the whole system would perform worse as a result. This is why multiple MPPTs are standard nowadays.

2.3.3 Power Optimizers

Power Optimizers are additional components that can be added to PV systems to improve efficiency, safety, robustness, and monitoring. They lie between the solar panels and inverters, so the solar panels are not directly connected to the inverter. Usually, they are mounted in a 2:1 configuration meaning that there are two solar panels per power optimizer. This is being done to find a balance between costs and performance. [14]

Optimizers have a built-in MPPT which constantly optimizes the connected modules. This is one of the reasons you can get more performance from optimizers compared to traditional systems. As the MPPT only needs to optimize 2 modules. This means that if 1 module is broken or producing worse the whole string is not affected.

The second big thing that optimizers do is they can adjust their output voltage and current independently of the input voltage. For example, if the input voltage of the two connected modules is 98 V. But the system is turned off, the optimizer only outputs 1V. This means that even during daytime the strings can be safe to touch (< 50 VDC) compared to traditional systems where the voltage is always dangerous (typically 500 - 900 VDC) during daylight hours. [15]

3 Communication

Communication is an ever-important part of installing PV systems. Customers nowadays are savvier and demand more detailed information. More detailed information also helps operations and maintenance (O&M) teams to make better and more efficient decisions.

The XM-200 data logger from Meteocontrol is the data logger used in this work. It was chosen as it was a customer requirement.

Communication between the XM-200 data logger and the inverter can be done in two ways: Modbus RTU and Modbus TCP. Modbus TCP is the interface used in this work as the inverters already need an internet connection to connect to the monitoring platform. In this case, a network switch is required. Modbus RTU is also a valid option if the cable runs are long or if data security is a priority.

3.1 Sunspec Modbus

Using Modbus in the solar industry is nowadays an easy task as manufacturers have begun to standardize communication protocols. Most inverter and smart PV systems nowadays utilize an application layer on top of Modbus called Sunspec Modbus. “SunSpec Modbus is an open standard, referenced in IEEE 1547-2018, that enables interoperability amongst DER system components” [1].

What it essentially means is that in Sunspec Modbus there are guidelines on what information should be where and in what format it stored. For example, the Sunspec Modbus spec requires that measured values should not be stored in floating point formats. Instead, they employ a different format with scale factors. Therefore, each measured value has a corresponding scale factor.

For example, in SolarEdge inverters the frequency of the mains is stored with two decimal point accuracy. The stored value could for example be 5032 and the scale factor -2 this then results in $5032 * 10^{-2} = 50.32$.

3.1.1 Understanding the Specification

In the specification you have one mandatory model you need to implement which is model “1”. This model includes basic information about the device. This model always comes first, and the model ID will always be found at address 40000 (base 0). Below is an overview of this model:

Table 1 SunSpec Modbus model 1 mappings [16]

Address Offset	Name	Value	Type	Size	RW Access (RW)	Mandatory (M)	Static (S)	Label	Description
	common		group					Common	All SunSpec compliant devices must include this as the first model
0	ID	1	uint16			M	S	Model ID	Model identifier
1	L		uint16			M	S	Model Length	Model length
2	Mn		string	16		M	S	Manufacturer	Well known value registered with SunSpec for
18	Md		string	16		M	S	Model	Manufacturer specific value (32 chars)
34	Opt		string	8			S	Options	Manufacturer specific value (16 chars)
42	Vr		string	8			S	Version	Manufacturer specific value (16 chars)
50	SN		string	16		M	S	Serial Number	Manufacturer specific value (32 chars)
66	DA		uint16		RW			Device Address	Modbus device address
67	Pad		pad				S		Force even alignment

As shown the information here is very basic, such as the manufacturer of the device and type. After model 1 you can implement essentially any number of models from the 105 available. For example, the SolarEdge inverters used in this thesis have implemented model 103 (Inverter Three Phase) and 160 (Multiple MPPT Inverter extension model).

All models in the SunSpec Modbus spec have the same two registers “ID” and “Length” These define the model number and the length of it. For example, the common data in model 103 in SolarEdge inverters looks like this:

Table 2 SolarEdge inverter model 103 common data [17]

Address		Size	Name	Type	Units	Description
(base 0)	(base 1)					
40069	40070	1	C_SunSpec_DID	uint16		101 = single phase 102 = split phase 103 = three phase
40070	40071	1	C_SunSpec_Length	uint16	Registers	50 = Length of model block

As the table shows the first data point always tells what information model it is, in this case, model 103. The next register tells us how long the model is, in this case, 50 registers long.

This means that the next model can be found at address $40070 + 50 + 1 = 40121$ therefore the next information model can be found at address 40121. The datasheet indicates that here begins a new model:

Table 3 SolarEdge inverter model 160 common data [17]

Address		Name	Size	Type	Units	Description
(base 0)	(base 1)					
Header (Size: 2 words)						
40121	40122	ID	1	uint16	N/A	Value = 160 Multiple MPPT Inverter Extension Model
40122	40123	L	1	uint16	N/A	Model length

The table above reveals the next model 160 at address 40121. In this case, the model length is not defined in this datasheet as the length of the model depends on how many synergy units the inverter has [17].

These steps of reading the model IDs and lengths can be repeated until you read model ID: 0xFFFF and model length 0. This signifies that there are no more models implemented on the device. [16]

4 Hardware

This chapter presents an in-depth analysis of the components utilized in this thesis. Solnet uses in Finland exclusively SolarEdge products in non-utility scale installations (< 10MW). SolarEdge is a manufacturer of inverters and optimizers. And their whole business model is based on providing efficient and highly data-driven smart solar solutions. SolarEdge has one of the most advanced monitoring platforms where you can see data on a module resolution. This is enabled by their own optimizer and inverter combination for which they have developed a proprietary and patented communication protocol to communicate using the DC string cables. This means that no extra cabling or wireless access points are needed to get all the highly valuable information.

4.1 SolarEdge Systems

SolarEdge systems utilize optimizers to maximize performance, monitoring, diagnostics, and safety. The main thing that makes SolarEdge systems much safer than traditional PV systems is that when the power plant is shut down or encounters a problem. The voltage in the string is lowered to under 50 VDC in less than 5 min [18]. The optimizers in the SolarEdge system do not output voltages over 1V unless there is communication with the inverter.

This is not possible in traditional PV as the strings always have dangerous voltages during daylight. This voltage of course depends on the length of the strings but is generally in the 500 - 700V range in commercial PV systems. This data is from internal company documents analyzing 41 traditional PV sites. And that voltage is not only dangerous to humans but also a fire hazard if there is an arc.

4.1.1 Optimizer

Optimizers are one of the two main products, SolarEdge manufactures. Their optimizers range from small 400W single-module optimizers to 1400W models designed for two high-power modules. The SolarEdge optimizer used in this project is the P801 which is an 800W optimizer.

4.1.2 Inverter

SolarEdge has inverters in all market segments from small residential inverters to 330 kW utility-scale inverters. Their commercial three-phase inverters utilize their so-called “synergy technology” which means that the inverter is not a single large unit. Instead, it is divided into one so-called synergy manager and up to three so-called synergy units.

Below is a picture of a 100 kW SolarEdge inverter. As you can see there is quite clearly one manager and three synergy units.

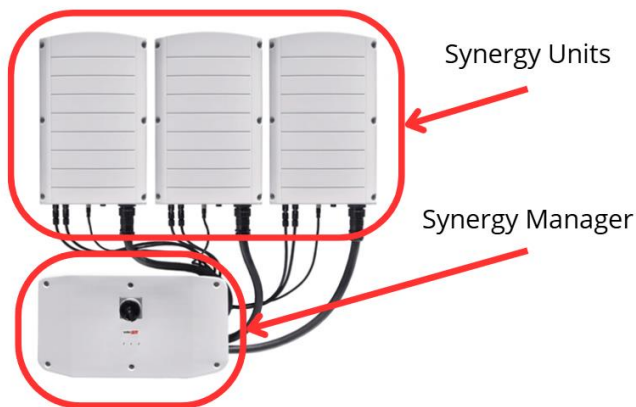


Figure 3 Picture of SolarEdge inverter system

The manager can be thought of as the brains or the hub of the inverter, it has all the complicated communication and processing circuitry. Meanwhile, the synergy units do the hard work of turning the DC power into AC power.

The manager functions as a hub for the inverter system. All the inputs and outputs of the PV system are connected to the manager. From the manager, there are then four cables connecting to the synergy units one AC Power cable, two DC cables, and one communication cable as can be seen in Figure 3. The manager is responsible for controlling the synergy units.

The synergy units receive DC power and convert it to AC power with up to 98 % efficiency. The units not only convert it into active AC power but also have the capability to supply or sink reactive power. This can be useful in stabilizing the grid especially, in utility-scale power plants. [19]

The inverters utilized in this project are one SE66.6K and one SE33.3K. These inverter powers are 66 kW and 33 kW respectively. Two smaller inverters were used instead of one 100 kW unit due to customer requirements. They feed into the grid via a three-phase mains connection.

4.2 Meteocontrol XM-200

The data logger used in this work is an XM-200 from Meteocontrol. It is a data logger designed for PV and battery energy storage systems (BESS). It is manufactured by Meteocontrol themselves, which enables a high level of integration with their SCADA platform. By having good integration with the cloud platform, the reliability and functionality of the system is improved. For example, the data logger can be fully controlled remotely giving high flexibility in terms of commissioning and different troubleshooting cases.

In this thesis, not all the available features will be utilized. The highly customizable software and the versatile I/O mean that this product can be adapted to a wide range of use cases. The XM-200 even supports analog inputs which means you can connect traditional current measurement coils directly to it making additional energy measurement easier and more cost-efficient.

4.3 Meteocontrol SI-RS485TC-T-MB irradiance sensor

In this work, an irradiance sensor is also used due to customer requirements. These sensors are useful to evaluate how well the system is working and in the long run, evaluate module degradation. Irradiance sensors are just essentially normal solar cells that have very well-defined characteristics. These irradiance sensors from Meteocontrol also have an inbuilt temperature sensor for the cell which is useful for making the results much more accurate as the power a solar cell produces is also dependent on cell temperature. These sensors also include integrated processing which allows for calibration and communication via digital protocols (Modbus-RTU via RS-485 in this case).

5 Software

Software is in an ever increasingly important role in the world, and this is also true for PV systems. This is even true for smaller PV systems that in the early days usually had little to no energy metering or remote monitoring. In the worst-case scenario, the PV system might have been broken for months or years. This is one of the reasons why monitoring is vital in PV systems to be able to quickly identify faults in the system and then react accordingly.

5.1 Meteocontrol VCOM Cloud

Meteocontrol VCOM cloud is a SCADA system that is designed for monitoring and control of PV and BESS systems. It has been built on a highly customizable base allowing it to be adapted for a wide range of use cases. One thing that makes VCOM a highly valuable tool is that it supports all major manufacturers of solar products. This means you can easily integrate a whole fleet of different PV systems into a single platform. This in turn means ease of use is greatly improved and means that chances for human error are minimized. [20]

5.2 SolarEdge monitoring

SolarEdge monitoring is one of the most advanced solar monitoring platforms and a vital tool for both customers and contractors. One thing that sets their monitoring apart is that you can get detailed info at a module resolution. This means that you can easily locate even small problems that would be inefficient to locate in traditional systems.

Below is a screenshot of how the physical layout looks in the monitoring platform. In this, picture it is quite easy to locate faults. In this example, you can see one module pair in the top right corner is getting slightly lower production this is most likely partial shading from the building. In the figure, you can see that one module pair is producing roughly half of the power (dark blue in the picture) which usually indicates that one of the two modules connected to the optimizer is broken. And at the bottom (also in dark blue) it looks like the optimizer is broken.



Figure 4 Screenshot from SolarEdge monitoring showing the production of a module array (Screenshot by author, 2025)

When you can view the PV system at this level of resolution you can quickly notice problems and discover problems, these problems could otherwise be difficult to discover. The other major feature of the monitoring platform is that you can remotely configure and adjust settings on the inverters. This reduces site visits and saves costs.

6 Planning

As with all projects, it is vital to have a solid plan before you start working. This plan will include both the plan for the physical commissioning works and the configuration of the system. Planning will be done by first assessing the goals for the specific site. After the goals are defined, a plan can be formulated. Afterward, the plan will be evaluated to improve it further.

6.1 Physical Works

As is usual with these kinds of projects the physical works are the simplest part of the work. In this case, the only physical work that needs to be done is installing the data logger. Of course, to get the data logger functioning it will need power and networking. This is also part of the physical work. The goals for the physical work are listed below:

- Install data logger and enclosure
- Install required supporting equipment (Ethernet switch, power supply)
- Install required cabling (AC, communication, and network)
- Install irradiance sensor
- Initial commissioning and testing

Below is a picture that was taken during the installation phase of the site (Q1 2025). The location of the data logger and the required cabling are shown in the picture. Based on the picture there should not be any problems with space during installation.



Figure 5 Location of the components in the system (Photograph by the author, 2025)

6.2 Configuring

To get the system fully functional it needs to be configured properly. This can be either simple or more advanced depending on customer requirements. This project falls somewhere in between. It is not the simplest nor the most advanced. The config will include simple alarms and the setup of a relevant view in VCOM.

- Put the details of the PV system into VCOM
- Configure the XM-200 on site
- Configure the SolarEdge inverters to activate the Modbus TCP ports.
- Configure the SolarEdge inverters to have a static IP address
- Add the XM-200 to VCOM
- Add the irradiance sensor and check that it is working
- Check that communication is working
- Configure the rest of the system alarms and graphs remotely

7 Commissioning

Commissioning in this work will include both the installation of the various devices and an initial configuration to verify that the wiring is correct and working. The work will follow the plan laid out in the previous chapter. It should be noted that only people with sufficient qualifications can work on mains voltages.

7.1 Installing enclosure and devices

Since there was a clear plan from the start. The placement of all components was well-defined in advance. The location of the data logger was quite tight but still acceptable. The physical work started by installing the enclosure for the data logger and power supply. The Onnline ONNFIN12C enclosure was chosen. It was chosen due to its affordability and size to fit all the components. Note that it is only IP40 rated therefore it cannot be installed outdoors or in moist environments.

Below is a picture of the enclosure with the devices installed. In addition to the data logger and its power supply, there is also a surge protection device (SPD) for the communication cable going to the roof for the irradiance sensor. This was a special customer requirement. The SPD used is specially designed for low-voltage communications.



Figure 6 The enclosure with the devices installed (Photograph by the author, 2025)

7.2 Wiring the Enclosure

With the enclosure and supporting devices installed the wiring can begin. The enclosure will be wired with the following diagram:

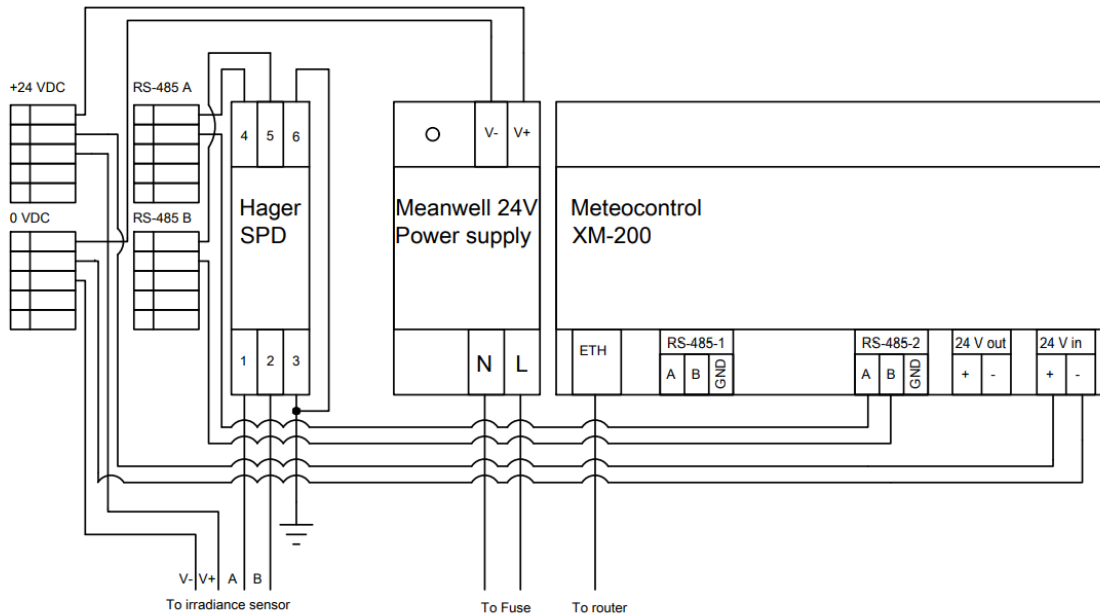


Figure 7 Wiring diagram of the enclosure

For all the non-mains wiring $0,8 \text{ mm}^2$ conductors are used. This is due to 2 pair $0,8 \text{ mm}^2$ solid conductor wire being affordable and easy to work with. For all the mains connections $2,5 \text{ mm}^2$ conductors are used. This is more than required for this circuit as it has a typical power of around 5 W and the power supply can only output 36 W . But $2,5 \text{ mm}^2$ cable is used to meet the dimensioning requirements of the fuse. These calculations are beyond the scope of this work. It should also be noted that only qualified electricians can perform this installation.

The final wiring is shown below.

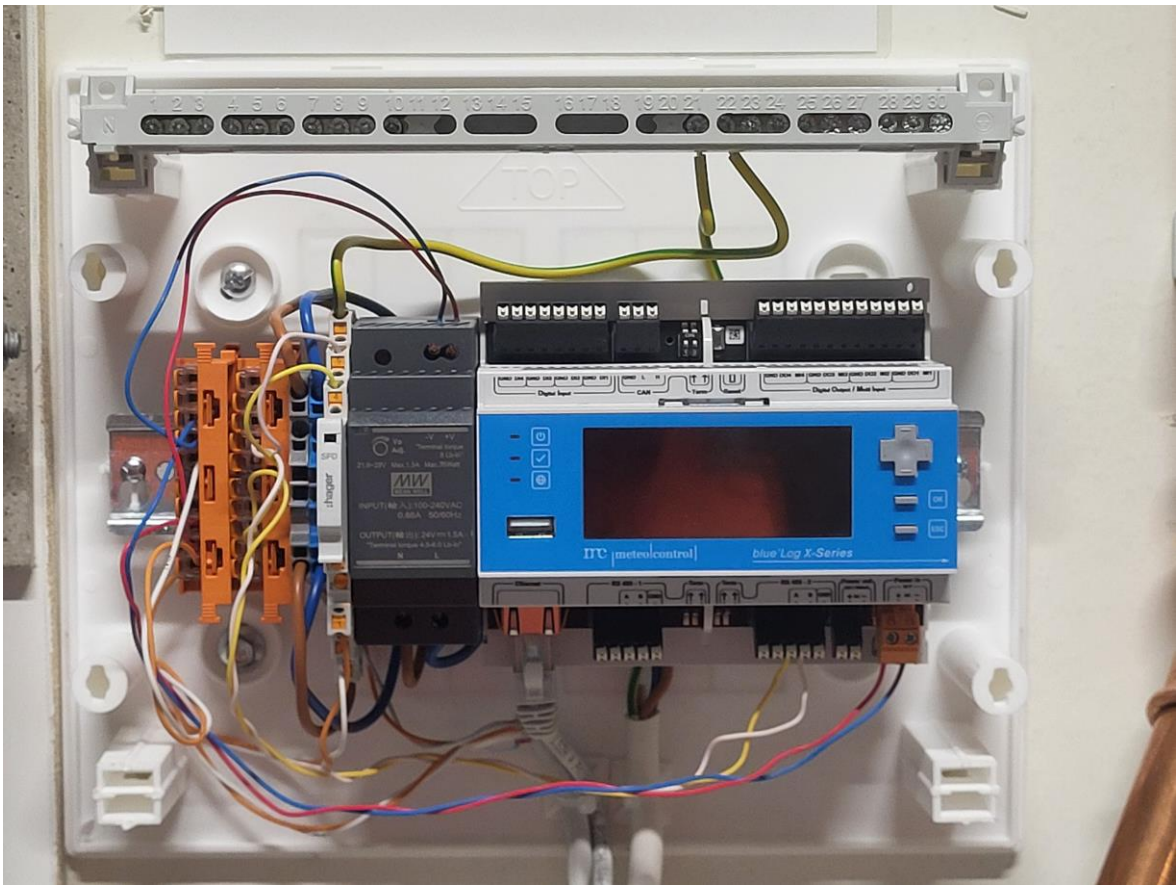


Figure 8 Picture of the final wired enclosure (Photograph by the author, 2025)

7.3 Installing the irradiance sensor

The irradiance sensor installation is quite straightforward. It requires four wires (+24V, GND, RS-485 A, RS-485 B).

A key advantage that makes installing different sensors to Meteocontrol easier is that the data logger can be accessed fully via the cloud. This means that while on the roof you can check whether it is working or not.

In the picture below the remote connection feature proved useful by enabling verification that the sensor was working.



Figure 9 Irradiance sensor installation and testing of the sensor via VCOM (Photograph by the author, 2025)

7.4 Initial Configuration

After the physical installation is completed. The next step is to configure the inverters' Modbus TCP port and change it to the industry standard port 502 instead of the default 1502. This is done using a phone app called "setapp" which is used to configure SolarEdge inverters. In the app, it is also important to configure the IP address as static. Otherwise, the Modbus TCP communication will terminate every time the DHCP lease ends.

After the inverters have been configured with the appropriate settings the XM-200 and VCOM cloud systems still need to be configured with a base configuration. To configure the system, it must be connected as shown in Figure 10. With this setup, all devices have an internet connection and can be directly accessed from the computer.

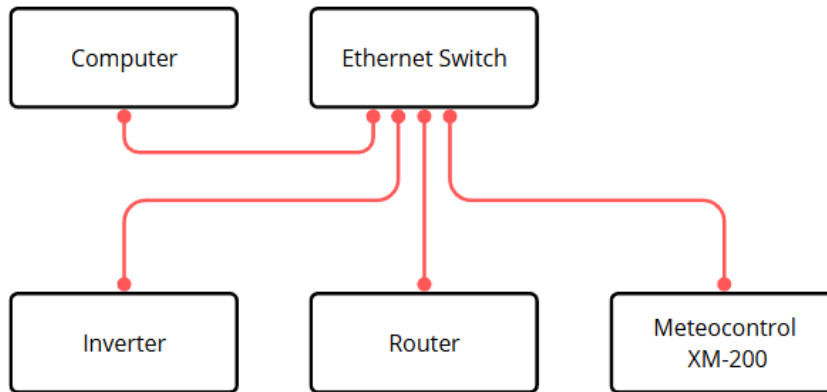


Figure 10 Ethernet connection diagram

The configuration of the XM-200 has been made very easy. It is quite close to a plug-and-play system. You select the manufacturer and interface to communicate via and then hit scan. This then scans all the IP addresses on the selected subnet. It then automatically reads the manufacturer data from the Modbus registers and configures the devices accordingly.

To configure the irradiance sensor, you need a bit more information as it uses Modbus RTU via the RS-485 bus. You need to know the baud rate, data format, and device ID. This data is written on both the sensor itself and the packaging. With these parameters, a scan will detect the irradiance sensor. To verify correct operation, similar to Figure 9 you can read real-time values from the device.

Device name ↑	Irradiance	Temperature
Meteoco...5-2 36	350.6 W/m ²	35.8 °C

Figure 11 Screenshot from VCOM showing irradiance sensor function (Screenshot by author, 2025)

8 Operation

This section focuses on VCOM and the different configurations needed. One of the most important things to set up correctly into VCOM is the technical data for the subsystems. Subsystems in this case refer to inverters but in different scenarios can vary. For example, a group of inverters or batteries could be a subsystem.

To ensure this information is accurate you need to look at the documentation for the installation. There you can find all the relevant information needed. Here is an example of a subsystem called INV 1 (short for inverter 1).

Technical Data:	Edit	Delete
Designation:	INV 1	
Power:	70.89 kWp	
Area:	321.7 m ²	
Tracking system:	Without tracking system	
Tilt:	11 °	
Orientation:	182 °	
Type of installation:	Flat-roof installation (elevated)	
System start-up:	26/3/2025	
Allocation of inputs:	1/1/1/1/0	
series-connected:	32/31/32/34/32	
Parallel-connected:	1/1/1/1	
Inverter type:	SolarEdge SE66.6k-6 MPPTs	
Number of inverters:	1	
Module type:	Trina TSM-440-NEG9R.28	
Number of modules:	161	

Figure 12 Correctly configured subsystem in VCOM (Screenshot by author, 2025)

When the subsystems are configured correctly the information is transferred correctly. When this is complete you can go to the main page and see all the values like this:

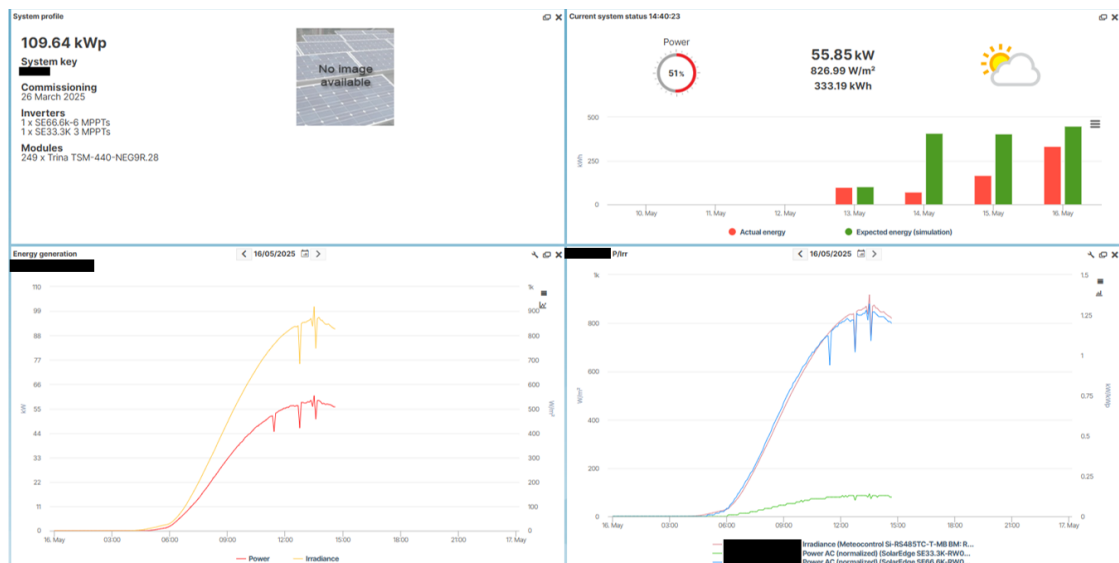


Figure 13 Screenshot from meteocontrol VCOM displaying the “cockpit” (Screenshot by author, 2025)

As you can see there is a lot of data and for some users, it could be too much. But this view, and every view is entirely customizable. You can arrange the windows how you want or have completely different information displayed. There are also different tabs that are user-configurable, you can also add new tabs.

A useful analysis to examine is the irradiance compared to the normalized power. This means that the power is divided by the installed capacity e.g. kW/kWp.

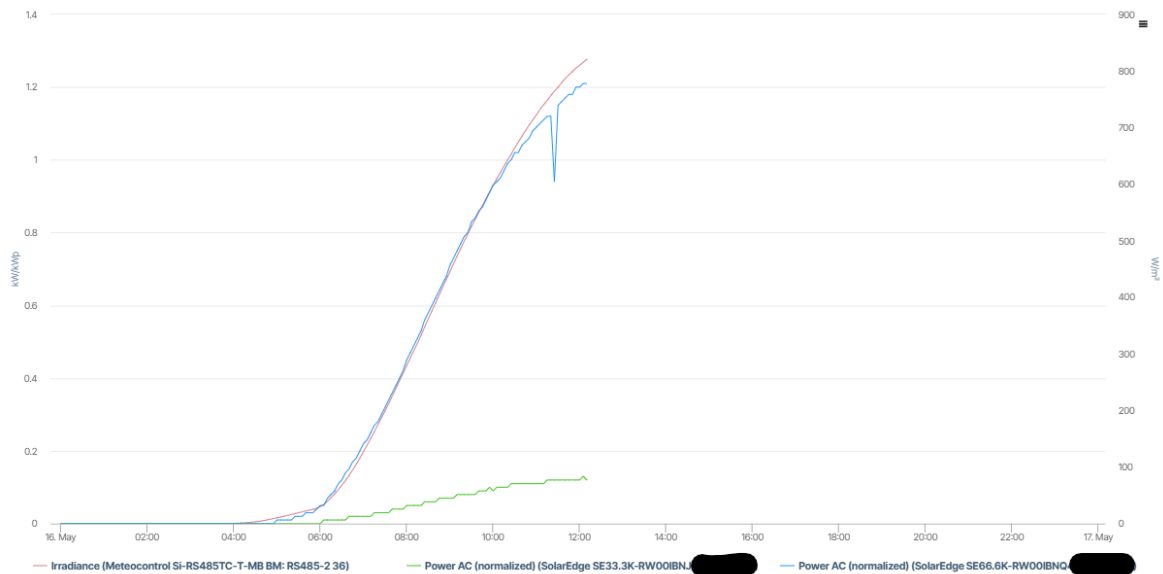


Figure 14 Graph of irradiance and normalized power (Screenshot by author, 2025)

In this case, it is clear that one of the inverters is not producing as much as it should. The red line is the irradiance in W/m^2 , and the blue and green lines are the inverters normalized power. You can easily see that the 66.6K inverter is working as expected but the 33.3K is not working as expected. The production is much lower than it should be.

This shows how useful it is to have an irradiance sensor. You can easily distinguish between just low production due to bad weather and low production due to faults.

8.1 Configuring alarms

As with most things in VCOM, you can configure it to your needs. There are several preset alarms that can be used, or you can make custom ones. In this case, these preset alarms are used as they meet customer requirements. The alarms used will be:

8.1.1 Total outage alarm

As the name implies, this alarm triggers if there is a total outage of production in the plant. This can be configured with delay parameters and what percentage is considered a total outage. In this case, a value of 5% will be used and a delay of 240 minutes, which equals four hours. This delay time is chosen because there can sometimes be faulty data or communication losses or some short maintenance. The long time is to avoid getting alarms in these situations.

8.1.2 Communication loss alarm

This alarm triggers when there has been a loss of communication with the data logger. This has three different severities of alarms which all can be configured with a custom time like in the picture below:

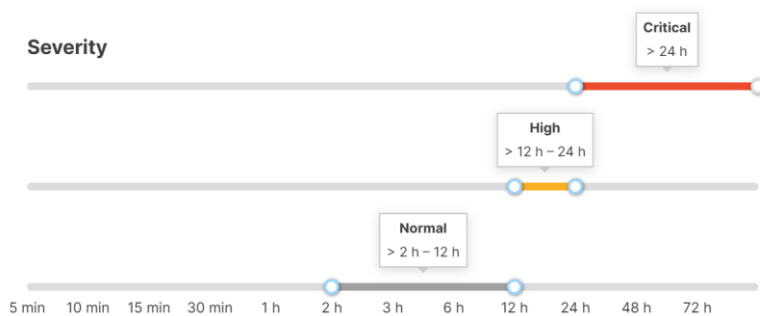


Figure 15 Configuration of communication loss alarm (Screenshot by author, 2025)

This is a very useful alarm as communication systems can sometimes get stuck and need to be restarted. Without the alarm, you would have to manually go through potentially hundreds of plants and check if the communication is working or not.

8.1.3 Data outage alarm

This alarm is triggered when the communication with the data logger still works (responds to ping) but the files received are either empty or in the wrong format. This can occur for many reasons. But it is usually a configuration issue with the data logger itself.

9 Summary and results

After all the configuring and physical installation, the goals that were set out initially were achieved. A functional SCADA system was implemented for a PV system and a plan was formulated. The system was made to meet customer requirements, which have all been successfully fulfilled. The final completed installation looks like this:

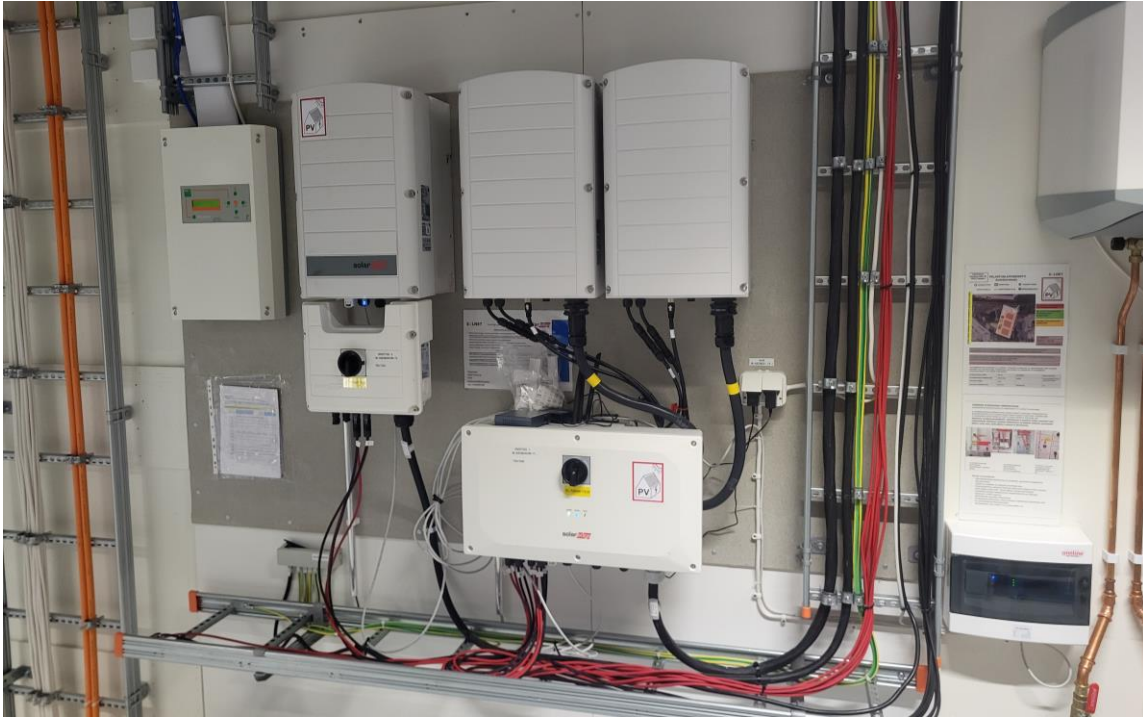


Figure 16 Picture of the final installation (Photograph by the author, 2025)

The plan that was laid out in Chapter 6 worked quite well for this site. Of course, it is difficult to evaluate a plan's effectiveness with only one site. At other sites, it might be more difficult to find a suitable place for the enclosure or locate a close-by and suitable mains connection. In this case both were easy.

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