SMART-GRID
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Document history

Project book
Industrial Power Systems (IPS)
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3	22-11-2021	IPS	IPS testing
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Preface

Assignment

With this project we will investigate how and whether it is possible to reconstruct a sustainable electricity network with production, storage and a ''Smart Grid'' algorithm with our Electrical Engineering Training System (e_PETS).

In concrete terms, we want to make a reconstruction of the port case in Arnhem where such a network will be installed between the N325, the IPKW and the Nieuwe Haven.

The aim of this assignment is to gain proficiency in performing mesh reconstructions in a controllable environment in a later phase of our study. The use of renewable energy makes matching supply and demand more complex. Smart Grid algorithms play a major role in matching energy supply and demand within the energy transition. This assignment concerns a preliminary investigation and we are preparing for further exploration of the possibilities and impossibilities of our electricity grid.

Chapter 1 job description

Job description

Between the N325, the Kleefse Waard industrial park and the Nieuwe Haven, solar cells are being built that together have a capacity of approximately 12 MW. In order to harmonize energy supply and demand, various parties are jointly experimenting with energy storage next to the solar field in the form of lithium iron phosphate batteries (LFP batteries) with a total capacity of 500 kWh. In neighbourhoods where a lot of solar energy is generated, the demand does not match the supply. Battery systems can temporarily store local energy so that it can be used locally at a later time.

In this project, just like in the port of Arnhem, you can experiment with energy storage, solar energy and wind energy with the aim of aligning energy supply and demand.

The HAN has an exclusive Electrical Power Engineering training system for energy technicians, with which such a setup, a 'smart grid' can be recreated. Our electricity grid at scale, with hardware and a SCADA interface, similar to those used in business.

The setup consists of 6 separate training modules, which once linked together form a 'smart grid'. By means of digital teaching material you will become acquainted with the generation of sun and wind, the demand for energy by end users, power stations and the electricity grid that transports the energy. With the different modules you build your own electricity network. Carrying out the 'smart grid' configuration is the ultimate challenge.

Chapter 2 analyses and research

2.1 Power grid

2.1.1 Electric grids

Low voltage
Low voltage refers to AC voltage up to 1,000 volts and DC voltage up to 1,500 volts. Low voltage therefore also includes the mains voltage of 230/400 volts that is used in companies and homes.

Medium voltage
Formally, the term 'medium voltage' does not exist. This is because the term is not described in the European high voltage standard EN-50110. In practice, the term is used, in particular by network operators, for the voltage between 1000 Volts AC or 1500 Volts DC and 25,000 Volts (25 kV).

High voltage
We are talking about high voltage at a voltage higher then 1,000 VAC and 1,500 VDC. But it's most common that we say high voltage when it's between 25,000 Volts (25 kV) and 220,000 Volts (220 kV).

Difference between AC and DC
Alternating Current (AC) flows first in one direction and then the other, continuously changing direction.
An AC voltage changes continuously between positive (+) and negative (-). A pole (connecting wire) is therefore very quickly alternating positive (+) and then negative (-) again.
Direct Current (DC) always flows in the same direction but it can increase or decrease. So there is always one pole (connection wire) that is negative (-) and one pole (connection wire) that is positive (+).

Transporting electricity
Traditionally, alternating current has been used for the transport of electricity, because the voltage can easily be changed with transformers and with virtually no energy loss. However, alternating current suffers from the skin effect, which means that there are more losses during transport than if direct current were used.

Image 2.1.1

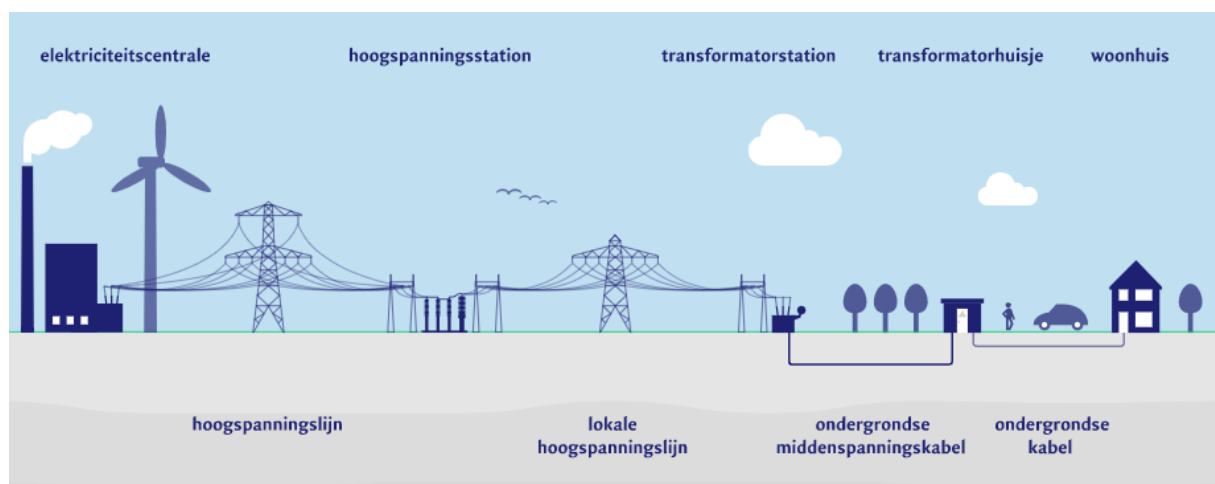According to AREI (Algemeen reglement op elektrische installaties)

Type	Voltage
Low voltage	< 1000 V
Medium voltage	> 100V and < 50.000 V
High voltage	> 50.000 V

According to IEC (International electronical commission)

Type	Voltage
Low voltage	< 1000 VAC
	< 1500 VDC
High voltage	> 1000 VAC
	> 1500 VDC

2.1.2 Three-phase systems

Three-phase systems are used especially in the field
of electrical energy technology to transport and distribute electrical energy via inter-regional, high-voltage grids and to supply local, low-voltage networks with electricity.

A three phase circuit is a system where the three phase is sent together from the generator (generation) to the load (your house for example) the difference between each phase is 120 degrees so a total of 360 degrees. The strength of the three-phase system is continuously this because all three phases are involved in developing the total power.

Because of the simple generation and transformation of three-phase signals and the benefits of three-phase machines compared with single-phase AC
machines, all public electricity grids today comprise three-phase systems. Low-voltage networks usually have a four-wire configuration with a grounded neutral conductor.
On arrival at a household, for example, the power is then distributed among separate AC lines. High-voltage networks usually have a three-wire configuration. A three-phase network's outer conductors are now designated in standard fashion as L1, L2 and L3, the neutral conductor as N. However, obsolete designations R, S and T are still occasionally used for outer conductors.

	L1	L2	L3	N	Protective ground
EU Hong Kong	▬	▬	▬	▬	▬

Image 2.1.2

Illustrated below is a three-phase generator's operating principle. Demonstrated here for a better understanding is a simplified generator whose rotor comprises a permanent magnet. In real three-phase generators, the rotor usually comprises an electromagnet.
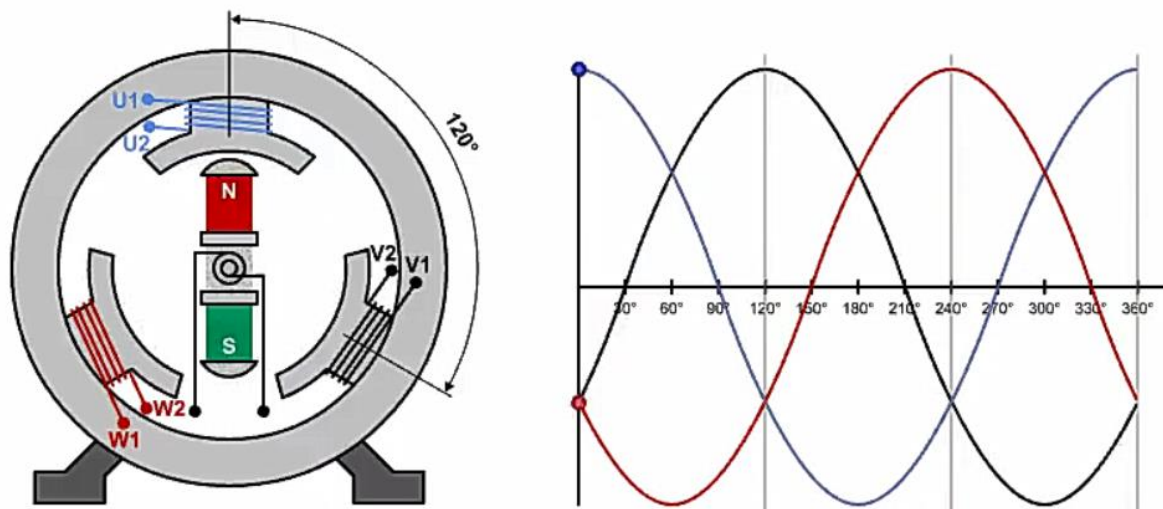
Image 2.1.3

The stator essentially comprises three coils each wound around an iron core.
The three iron cores' outer sides are magnetically coupled via a ferromagnetic circuit. The inner face of each iron core comprises the pole pieces. Bearing the three phase coils respectively,
these pole pieces are located with a mutual, spatial displacement of 120° inside the generator. The rotor is driven at a constant angular speed, thereby inducing sinusoidal voltages
in the coils. Each voltage signal attains its positive maximum when the rotating magnet's north pole passes the centre of the corresponding pole piece, and its negative maximum when the magnetic south pole passes this point. Because the three pole pieces
are mutually offset by 120°, the induced voltages exhibit a similar phase shift of 120°. Rotors at power plants always turn an exactly steady rate, producing a fixed voltage frequency of 50
Hz which cannot be changed by the end user. The voltage value is also maintained very precisely at a constant level.

star circuit

With a star connection you have four wires, three of these wires are the phase wires, the fourth is the N (neutral). The neutral is taken from the star point, see figure 3. The star connection is preferred for long-range transmission because a star connection has a neutral point. When equal currents flow through all three phases, it is called balanced current. If the current in no phases is equal, then it is an unbalanced current. In a balanced condition, no current flows through the neutral. When there is an unbalanced current, the neutral has an essential role. It will divert the unbalanced flow to the ground. And protect the transformers. Unbalanced current affects the transformer and it can also cause damage to the transformer

10
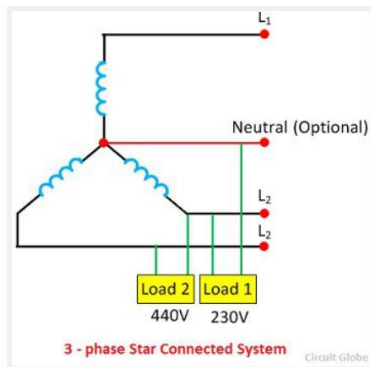
Image 2.1.4

Delta circuit

In a delta circuit there are three wires instead of four like a star connection. In a delta connection, also called a triangle,
no neutral is included. Normally, the delta connection is preferred at
short distances because of the problem of unbalanced current in a circuit.
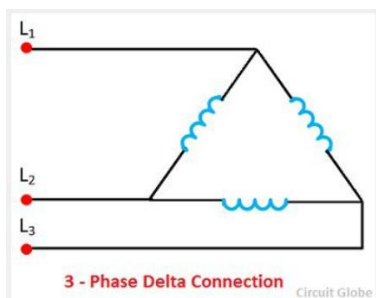
Image 2.1.5

Connection of charges in three-phase system

The loads in the three-phase system can also be connected in the star or delta. The three-phase loads connected in the delta and star are shown in the figure5.
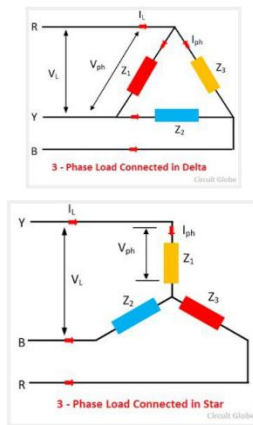
Image 2.1.6

The three-phase load can be balanced or unbalanced. If the three loads (impedances) Z1, Z2, and Z3 have the same magnitude and phase angle, then the three-phase load is a balanced load. Under balance condition, all phases and line voltages are equal.

2.1.3 Transformers

What are transformers

Transformers are electrical devices consisting of two or more coils of wire used to transfer electrical energy by means of a changing magnetic field.

The reason for transforming the voltage to a much higher level is that higher distribution voltages implies lower currents for the same power and therefore lower I^2*R losses along the networked grid of cables. These higher AC transmission voltages and currents can then be reduced to a much lower, safer and usable voltage level where it can be used to supply electrical equipment in our homes and workplaces, and all this is possible thanks to the basic Voltage Transformer.

A transformer basically is very simple static (or stationary) electro-magnetic passive electrical device that works on the principle of Faraday's law of induction by converting electrical energy from one value to another. The transformer does this by linking together two or more electrical circuits using a common oscillating magnetic circuit which is produced by the transformer itself. A transformer operates on the principals of "electromagnetic induction", in the form of Mutual Induction. These two coils are not in electrical contact with each other but are instead wrapped together around a common closed magnetic iron circuit called the core.

Transformers in circuits
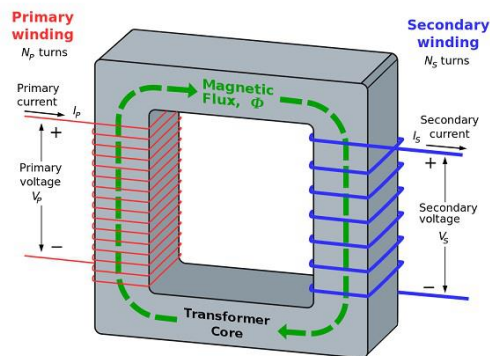
Image 2.1.7

From the above figure, it is evident that few notations are common. Let us try to have a note of them. They are –

- N_p = Number of turns in the primary winding

- N_s = Number of turns in the secondary winding

- I_p = Current flowing in the primary of the transformer

- I_s = Current flowing in the secondary of the transformer

- V_p = Voltage across the primary of the transformer

- V_s = Voltage across the secondary of the transformer

- Φ = Magnetic flux present around the core of the transformer.

These are some terms that are used and you should know what those terms are. When you talk about transformers. Transformers in circuits are a little bit simplified to the picture below

Image 2.1.8

This is in the case that there is no impedance in the circuit.

As the number of turns of primary and secondary windings affect the voltage ratings, it is important to maintain a ratio between the turns so as to have an idea regarding the voltages induced.

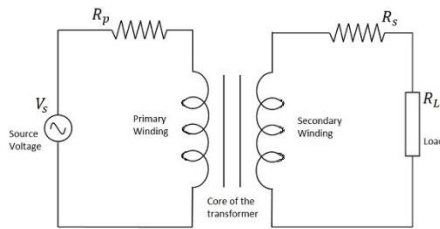The ratio of number of turns in the primary coil to the number of turns in the secondary coil is called as the "turns ratio" or "the ratio of transformation". The turns ratio is usually denoted by N.

$$N \ = \ Turns\ ratio \ = \ \frac{Number\ of\ turns\ on\ Primary}{Number\ of\ turns\ on\ Secondary} \ = \ \frac{N_p}{N_s}$$

Image 2.1.9

The ratio of the primary to the secondary, the ratio of the input to the output, and the turns ratio of any given transformer will be the same as its voltage ratio. Hence this can be written as

$$\frac{N_p}{N_s} \ = \ \frac{V_p}{V_s} \ = \ N \ = \ Turns\ ratio$$

Image 2.1.10

Real Transformers

Often for initial design calculations, we can assume that a transformer is ideal. However, a better model is needed for accurate calculations in the final stages of design. Moreover, a better understanding of transformers and their limitations is gained by considering a refined model. The equivalent circuit of a real transformer is shownbelow. The resistances R1 and R2 account for the resistance of the wires used to wind the coils of the transformer.
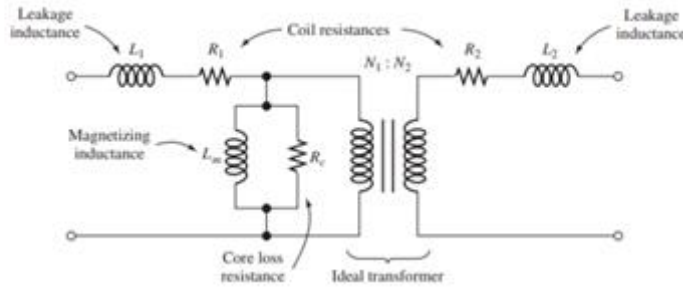
Image 2.1.11

For the ideal transformer, we assumed that all of the flux links all of the turns of both coils. In fact, some of the flux produced by each coil leaves the core and does not link the other coil. We account for this leakage flux by adding the inductances L1 and L2 to the ideal transformer, as shown in Figure above us. In discussing the ideal transformer, we assumed that the core reluctance was zero and ignored core loss. This meant that zero magnetomotive force was required to establish the flux in the core. Neither of these assumptions is exactly true. The magnetizing inductance Lm shown in Figure 14.28 accounts for the nonzero core reluctance. The current needed to establish the flux flows through Lm. Finally, the resistance Rc accounts for power dissipated in the core due to hysteresis and eddy currents.

Regulation and efficiency

Regulation and Efficiency Because of the elements L1, L2, R1, and R2, the voltage delivered to the load side of a transformer varies with the load current. Usually, this is an undesirable effect. The regulation of a transformer is defined as

$$\text{percent regulation} = \frac{V_{\text{no-load}} - V_{\text{load}}}{V_{\text{load}}} \times 100\%$$

Image 2.1.12

in which V_{noload} is the rms voltage across the load terminals for an open-circuit load and Vload is the rms voltage across the actual load. Ideally, we usually want the percentage regulation to be zero. For instance, poor regulation in a residence would mean that the lights dim when an electric clothes dryer is started. Clearly, this is not a desirable situation. Because of the resistances in the transformer equivalent circuit, not all of the power input to the transformer is delivered to the load. We define the power efficiency as

$$\text{power efficiency} = \frac{P_{\text{load}}}{P_{\text{in}}} \times 100\% = \left(1 - \frac{P_{\text{loss}}}{P_{\text{in}}}\right) \times 100\%$$

Image 2.1.13

in which Pload is the power delivered to the load, Ploss is the power dissipated in the transformer, and Pin is the power delivered by the source to the transformer primary terminals.

-r. Hambley

2.1.4 Power storage

Having a 12 MW installed power and a battery of 500 kWh, the project will have to make an intelligent power storing. It is going to be used a LFP battery meaning that the power is stored as electrochemical potential[1] between a lithium ferrophosphate (LiFePO4) cathode and a graphitic carbon electrode as the anode[2].

The battery is needed because the demand is constantly changing in time, so there will be certain intervals of time when the electricity production exceeds the power demand and the power in excess should be stored in order to maximize the efficiency of the system.

In order to store solar and wind energy, there are some systems that can be used, the most common being AC coupled system and DC coupled system. The DC system is best for small, generally DC oriented applications as this is the simplest and the cheapest.

The AC Coupled Systems are better for high power system, which would be the case in the Koningspleijn solar park[4]. This is because high power AC technology is easier to access and cheaper.

This is formed of the following components: the solar panels, a solar inverter, a multi-mode inverter and the battery[3].
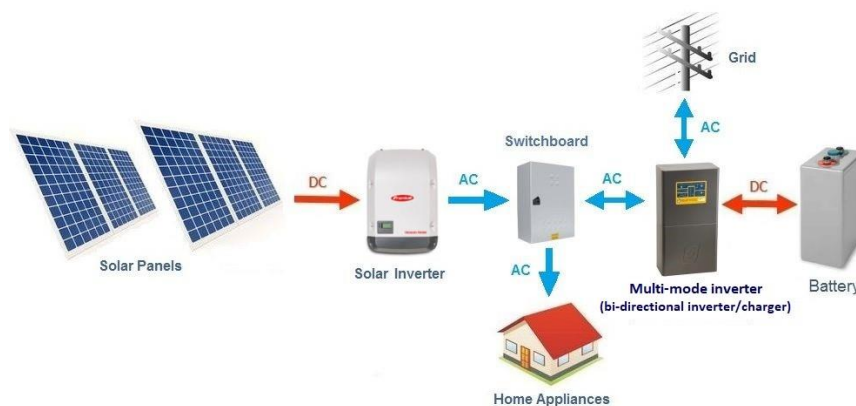
Image 2.1.14

The main advantages for this kind of system are:

- Higher efficiency when used to power AC loads during the day such as air-conditioning, pool pumps, and hot water systems (up to 97% efficient).

- Generally lower installation cost for larger systems above 6kW.

- Can use multiple string solar inverters in multiple locations (AC coupled micro-grids)

- Most string solar inverters above 3kW have dual MPPT (maximum power point tracker) inputs, so long strings of panels can be installed at different orientations and tilt angles.

- Advanced AC coupled systems can use a combination of AC and DC coupling

Of course, every system has disadvantages, these are the biggest:

- Lower efficiency when charging a battery system - approx. 85% to 90%

- Solar Inverter capacity may be limited to the Inverter-charger size

- Lower efficiency when powering DC loads.

2.1.5 Smart Grids

Introduction.

The current energy grid has been developed over the years to transport energy from the suppliers (Large power plants, e.g. gas plant) to the consumers. Due to this development, the consumer is very dependent on the supplier of reliable energy. However, this also brings advantages. The supplier can, for example, match the supply of energy to consumer demand.

Development of renewable energy sources.

Today we are in a transition between old-fashioned fossil energy production and renewable energy production. This is necessary to meet the climate targets in the future and is also necessary to obtain sufficient energy for the future. Nowadays there is a lot of development in renewable forms of energy, such as wind turbines on land and sea. Furthermore, the development in solar energy has also increased considerably, as a result the price has also fallen considerably. This has made it possible for consumers to meet their own energy needs. It also makes it possible to supply other energy back to the energy grid.
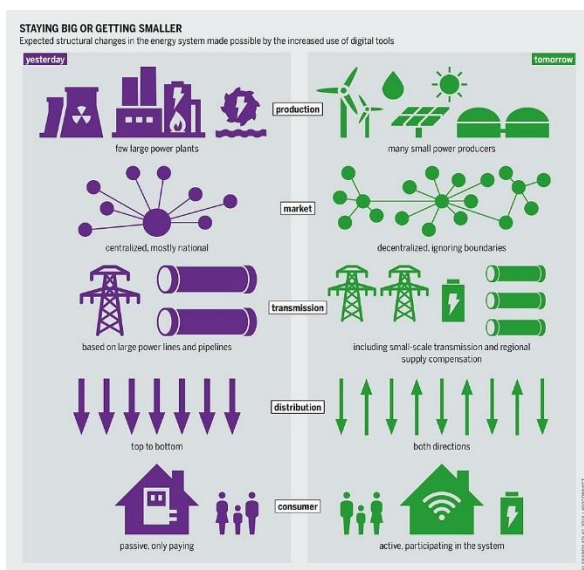
Image 2.1.15

Problem old power grid.

The problem that now arises is that the energy production from sun and wind cannot be predicted. It may be that the wind blows less hard or that the sun shines less brightly. This makes it very difficult for the energy supplier to meet the other needs. This is also undesirable when there is too much energy on the grid. The current energy grid has also not been developed for the transport of energy at consumer level, which makes the energy grid unreliable, and it can happen that consumers run out of energy.

Solution Smart Grid.

The solution is to make the energy grid smarter and more reliable. This requires storing excess generated energy when it is not in use. This can be done at the consumer level by placing batteries in houses that can store the extra energy generated. However, this can also be applied on a larger scale, for example in a village or city. These batteries can then provide successful energy when, for example, it is later in the evening.

Image 2.1.16

Furthermore, it is also necessary to reduce the peaks in energy demand, this can be achieved by means of smart switching systems to, for example, switch on the dishwasher at night when the energy price is low or at a time when there is too much energy on the grid. is present.

2.2 Research software and SCADA

During the Smart-Grid project we are doing research on the Lucas Nülle panels and SCADA software. We started with following the LabSoft courses and did some extended research on the SoftPLC and SCADA since there is not yet much information about that subject. In this document you can find all relative information.

2.2.1 SCADA structure

For the realization of the Smart-Grit project, SCADA (Supervisory Control And Data) is used. With this program it is possible to collect, transmit, process and visualize data from measurement and control signals. SCADA systems are common in industrial environments, for example for automating production lines or for monitoring/visualizing data and statuses of installations.

SCADA often runs on a PLC (Programmable Logic Controller). A PLC is a device that contains a microprocessor with which it can control input/outputs. Even in an industrial environment you see a PLC a lot, making it an indispensable part for any form of automation.

2.2.2 Communication interfaces

Additional research has been done into the communication between hardware and software. It was investigated how the different communication protocols are structured and how they work. Furthermore, it was also investigated how the SCADA system works with the Lucas Nulle modules.

There are different communication interfaces to communicate with the different devices on each test panel, using such an interface the computer can read/control outputs and outputs. The interfaces that Lucas Nulle uses are:

- USB
- Ethernet
- Rs485

USB-interface

USB stands for Universal Serial Bus and is widely used to connect peripherals to computers. A USB connection consists of four wires: red is 5 volts, black is zero, white is data and green is data+. The data wires are used to send data by means of variable voltage between the data and data+.

USB Type A   USB Type B   USB 3.0   USB Mini   USB Micro   USB Type C   USB Micro B

Image 2.2.1: USB-Types

Ethernet-interface

Enternet is a network standard with which computers in a LAN communicate with each other, this technique is widely used to connect to the world wide web. There are many cables over which the Ethernet protocol can be used, but Cat5e is the most popular.

In a Cat5e there are four pairs of veins the colors are: white / blue, blue, white / orange, orange, white / green, green, white / brown and brown.

Each device has its own IP address, making it possible to communicate with any device, using the IPv4 protocol for this.

RS485 interface

Rs485 is a serial connection that is common as a fieldbus in the industry, In the lab we use four-nice connection. This consists of four signal lines: TxA, TxB, RxA and RxB.
With this protocol it is possible to send and send data.
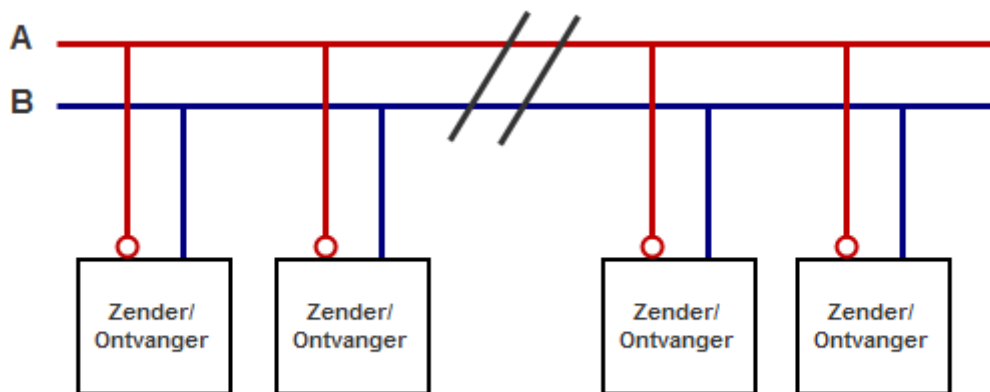
Image 2.2.2: Connection

With the help of these various communication protocols it is possible to communicate with the different Lucas Nulle modules using the SCADA software. For these modules templates have been developed by Lucas Nulle, which can also be called in the SCADA environment.

2.2.3 Research folder structure

In the SCADA environment we work with multiple types of files, these consist of:

- File = The PLC program
- PVC File = The SCADA program that can be opened in Designer and viewer
- Panel designer = Here "templates" can be created that can be used in the PVC File.

Type

File
PVC File
Panel Designer

Image 2.2.3: Folder

2.2.4 SCADA- viewer and designer

In the Lucas Nülle environment there are two scada programms. You have SCADA viewer and Designer. Just like the name already tells you in the viewer you are only allowed to "view" the SCADA projects and put them in simulation.
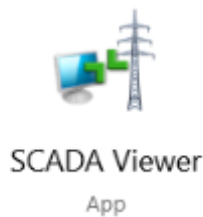
SCADA Viewer
App

Image 2.2.4: Icon SCADA viewer

In the designer you can design your own SCADA files and edit the already existing ones provided from Lucas Nülle. To access the designer you will need a valid license.

SCADA Designer
App

Image 2.2.5: Icon SCADA designer

2.2.6 Instruments

Instruments contain all "added" instruments. In this case it is the Quality meter, the logger and the PLC.

Image 2.2.6: Instruments

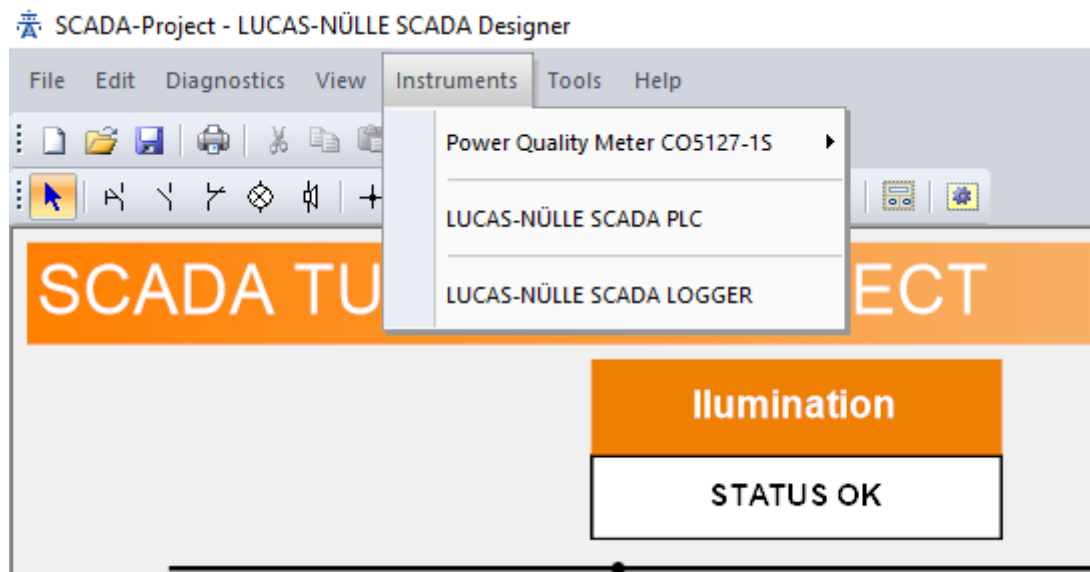To add Instruments: Settings and then "ADD". If no connection can be made, the IP addresses must be checked. This can be done by standing on the instrument and pressing "properties".
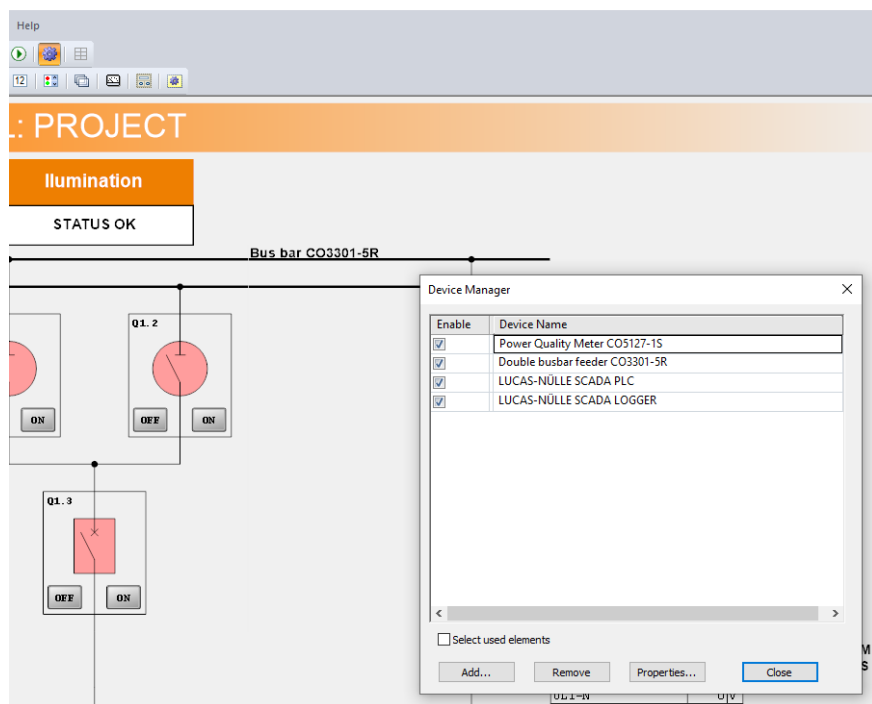

Image 2.2.7: Device manager

The correct PLC addresses can be found on the LN signs. These must be equal to the properties of the instruments within SCADA.
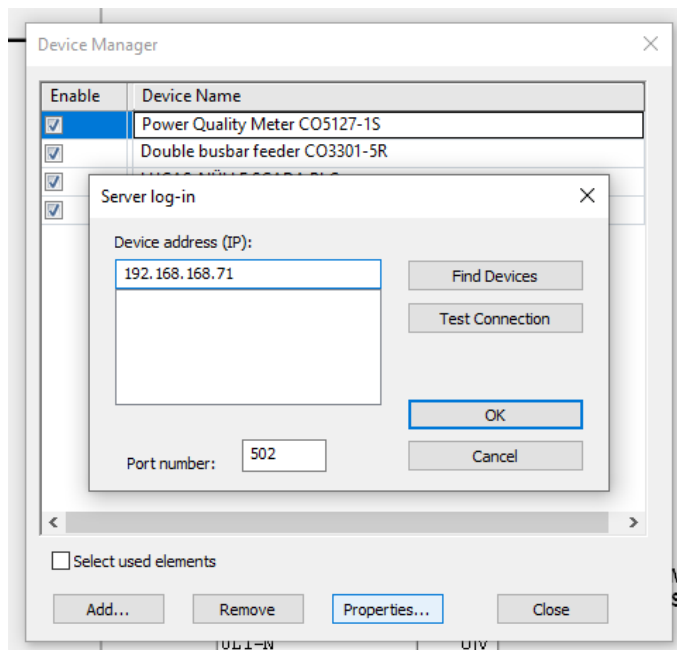
Image 2.2.8: Properties

2.2.7 Soft PLC

There are various types of PLCs (Programmable logic controller). First you have the traditional PLC**.** The traditional PLC consists of a CPU with its own housing and internal working memory. Usually, memory cards are used as storage memory. Think of an MMC card of a digital camera. The PLC that controls its outputs based on the information on its various inputs.

Image 2.2.9: Traditional PLC

Lucas Nülle uses the soft PLC.

The soft PLC is a PLC that runs as software on a PC or an embedded PC with, for example, WinCC. With an interface card and driver software, it communicates with the outside world. This communication normally takes place via a standard industrial bus system such as profibus or Modbus. New generation of embedded soft PLCs in small but powerful micro-PCs can also use Profinet as a means of communication in addition to Profibus or Modbus.

SoftPlcsare increasingly beingused. The reason for this is that they have lower installation and maintenance costs. Therefore, they are generally less expensive.

Image 2.2.10: Soft PLC

2.2.8 Software environment

According to IEC 61131-3 international standard (International Electrotechnical Commission),there are 5 programming languages to choose from when writing PLC control programs, two of which are textual and the other three graphic:
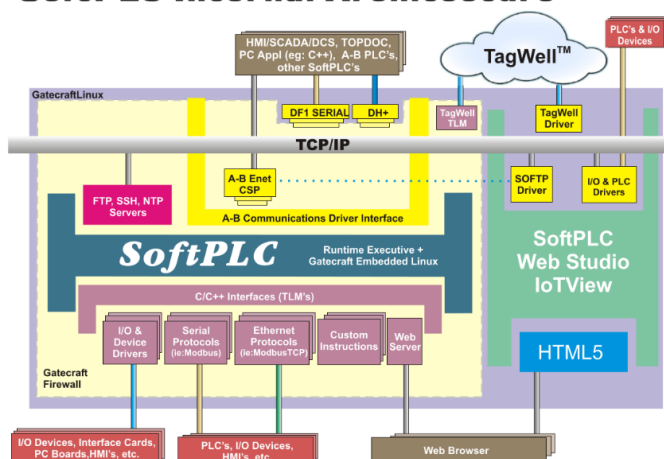
- Ladder Diagram (LD);
- Structured Text (ST);
- Instruction List (IL);
- Function Block Diagram (FBD);
- Sequential Function Chart (SFC).

The LUCAS-NÜLLE SCADA PLC is software for developing PLC programs. It consists of a screen-oriented editor for the languages "Instruction List (IL)" and " Structured Text (ST)". Although the compiler works according to this standard, it does not support all functions.

Structured text

Structured Text is a high-level language, representing a combination of three programming languages: Basic, Pascal and C. This language gives the opportunity to work with inputs and outputs, with different statements such as for, while, if and case.

It is easy to implement complex algorithms and work with mathematical functions. The disadvantage is that this language is more difficult to debug than a graphical language.

```
 1  IF #start = 1 THEN
 2      //comment
 3      "Max_nr" := #Array[0];
 4      FOR #i := 1 TO 10 DO
 5          // Statement section FOR
 6          IF #Array[#i] > "Max_nr" THEN
 7              "Max_nr" := #Array[#i];
 8          END_IF;
 9      END_FOR;
10  END_IF;
11
```

Image 2.2.11: Code structured text

Instruction list

Instruction text is a low-level language similar to the assembly language. A program consists of a series of instructions, displayed as in an assembly program. There are some common operations, such as addition, division, multiplication, and subtraction. There are also operations that make it possible to jump to a label and to call a function.

Instruction List makes the program compact and offers great processing speed. The disadvantages of this language are its structure and syntax. It is difficult to debug a large list of instructions.

```
ld      true
st      blinker.run
ld      t#1s
st      blinker.cycle
cal     blinker

ld      blinker.q
st      trigger.clk
cal     trigger

ld      trigger.q
jmpnc   LBmodulo
ld      counter
add     1
st      counter

LBmodulo:
ld      counter
lt      4
jmpc    LBout
ld      0
st      counter

LBout:
ld      counter
eq      0
```

Image 2.2.12: Code instruction list

PLC program

Code is written in the PLC to be able to read out certain data and perform actions. A PLC program should have a number of important components.

Adding variables

As seen with the SCADA, the various components can be added. In the Lucas Nülle environment, the inputs, outputs and statuses of the components can be read out. By fetching these addresses, the variables must be added.

By pressing Edit -> insert list of variables from the PLC and selecting the quality meter, all available variables with addresses of the relevant quality meter can be seen. Here the choice can be made which ones should be added in the software or they can all be added.
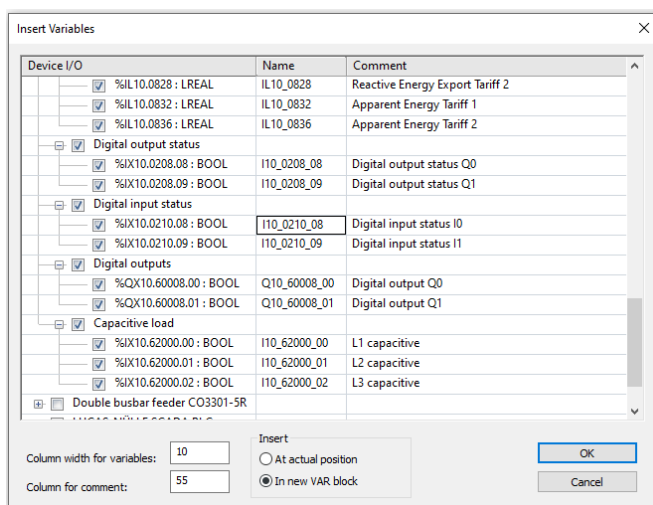

Image 2.2.13: Insert variables

By pressing "ok", the variables are added. The names can be adjusted as desired. In this way you make it clearer to yourself and others in the program what the input / output or status does.

```
(*Variable declaration*)
var
(* Power Quality Meter *)
(* Input bools *)
  I0_status      AT %IX10.0210.08 : BOOL;          (* Digital input I0          *)
(* Output bools *)
  Q0_ON          AT %QX10.60008.00 : BOOL;         (* Digital output Q0         *)
  Q1_OFF         AT %QX10.60008.01 : BOOL;         (* Digital output Q1         *)
(* Input values *)
  V_LN_avg       AT %ID10.0056 : REAL;             (* Average voltage VL-N      *)

(* PLC *)
(* Input bools *)
  PLC_ON         AT %IX0.0000.00 : BOOL;           (* I0                        *)
  PLC_OFF        AT %IX0.0000.01 : BOOL;           (* I1                        *)
(* Output bools *)
  PLC_Power_LED  AT %QX0.0000.16 : BOOL;           (* Q16                       *)
(* Output values *)
  Safety_Time    AT %QL0.0000 : LREAL;             (* PLC DO/ Value 1 Safety Time  *)
(* Marker *)
  PLC_ONOFF   : BOOL;
(* Timer *)
  FB          : TON;
(* Clock *)
  Blink       : CLOCK;
(* Function blocks *)
  OnOff : Toggle;

end_var;
```

Image 2.2.14: Added variables in cod

2.2.9 SCADA OPC

Open Platform Communications (OPC) offers a common bridge for the communication and data exchange on industrial automation. By running an OPC server it's possible to connect the different manufactures OPC-client to it, this way data transfer between the different platforms is possible.

Lucas Nülle provides within its SCADA software the possibility to integrate via SCADA OPC-Client process control hardware devices from different manufacturers or advanced data processing tools such as MATHLAB. This way it's possible to make complex automations way easer to implement in a real-world scenario.

Chapter 3 Tranings modulles

Every Tuesday we will work on different training modules, these are modules by Lucas Nuelle. These modules will help us to understand different topics of the smart grid.

These training modules are especially for IPS professionals. These are the training modules that we will make on Tuesday in the early weeks of the project. The goal is not to finish these modules as quickly as possible and to work through them as hard as possible. But to make every assignment correct and, above all, to understand it. Because we need this later in the project and then it is certainly important that we cover the topics of the smart grid. And understand Lucas Nuelle's signs.

- Professional photovoltaics

- Energy management

- Investigating busbar systems

- Wind power plants with dfig

3.1 Professional photovoltaics.

On Tuesday September 7, 2021 we started the training module of the solar panels.

Our goal is to understand. how the solar panel works. When the most energy is generated. How much can a solar panel generate. How the solar panel is connected in a system. What it takes to have the solar panel of your house supplied with energy. And of course how the solar panel works with the grid.

We start by looking at what a solar panel does with light.

Image 3.1.1

Our first setup here allows us to experiment what a solar panel does. When we vary the amount of light we put on the solar panel.

The results of the experiment. The y-axis shows the amount of volts. On the X-axis the irradance /w/qm. Irradance is the power per unit area of the incident electromagnetic radiation on a surface.

From this experiment we can get that the more irradance /w/qm there is the more the solar panel will deliver.
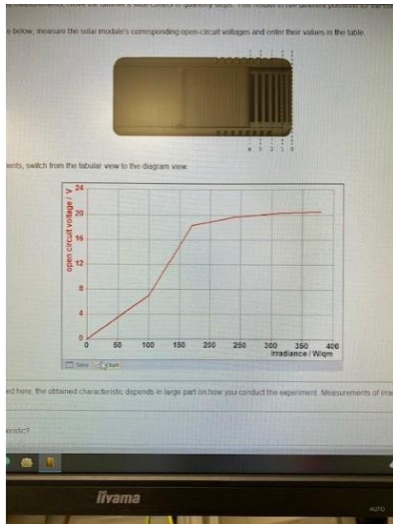
Image 3.1.2
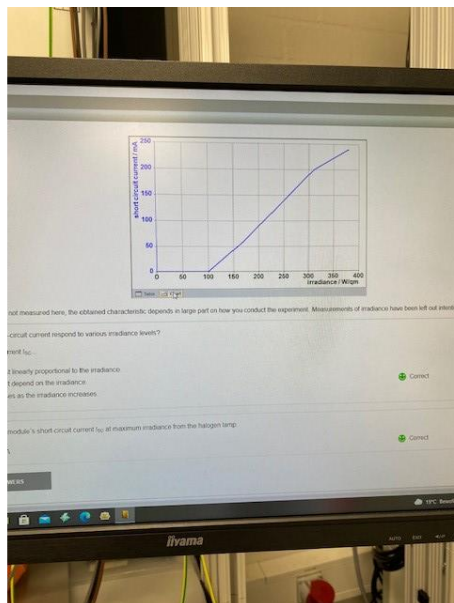
Image 3.1.3

Here we now have the current on the y-axis. You can see that the current increases almost linearly with the irradance.

We look at what shade does to the solar panel graph. We were able to simulate this ourselves with labsoft.

info@chargeup-noord.nl. (z.d.). *Waarom kiezen voor een 3 fase omvormer voor uw zonnepanelen?* chargeup. Geraadpleegd op 4 oktober 2021, van https://chargeup-noord.nl/waarom-kiezen-voor-een-3-fase-omvormer-voor-uw-zonnepanelen/

Image 3.1.4

In   *Image 3.1.4* you can see what shadow does on a solar panel.

The solar panel supplies a DC voltage. But your house runs on ac. So now it also takes something to make this happen. During the experiments we worked with an inverter. This is necessary to convert the dc voltage coming from your solar panels into an ac voltage.

Image 3.1.5

In *Image 3.1.5* you see the inverter that we used, this is a 3-phase inverter. The choice of a 1 phase or three phase depends on what you have in your house, there will be three or 1 phase. Nowadays 3 phase is widely used. to be able to take more power at the same time or to supply it back. A 1-phase inverter is cheaper and therefore easier for small installations. The 1-phase inverter can only run up to a maximum of 5000kw. So for higher you definitely need a three phase inverter.

Inverter finding.

During our research we have found out that the inverter requires a minimum power of 40W to operate. However, the irradiance is not always sufficient to supply enough power to the inverter. Therefore we have decided to set an minimum power limit for the inverter.

info@chargeup-noord.nl. (z.d.). Waarom kiezen voor een 3 fase omvormer voor uw zonnepanelen? Chargeup. Geraadpleegd op 4 oktober 2021, van https://chargeup-noord.nl/waarom-kiezen-voor-een-3-fase-omvormer-voor-uw-zonnepanelen/
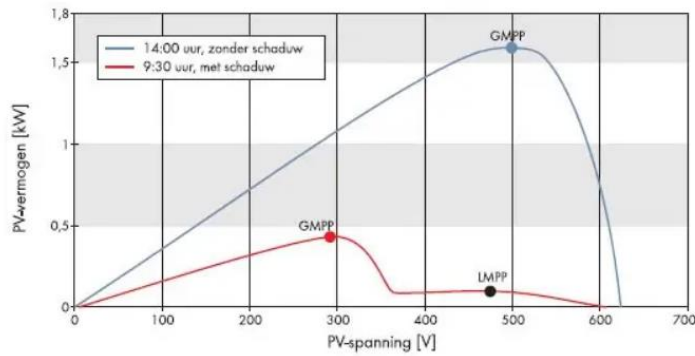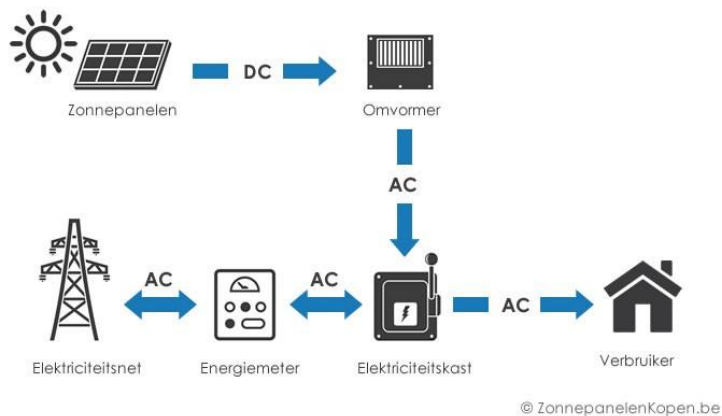

Image 3.1.6

This is how it works with the solar panels the sun shines on the panels. The inverter converts it to AC. Then the power demanded by the house is transformed into the house. When the solar panels supply more than the house needs, the rest of the energy is returned to the grid.
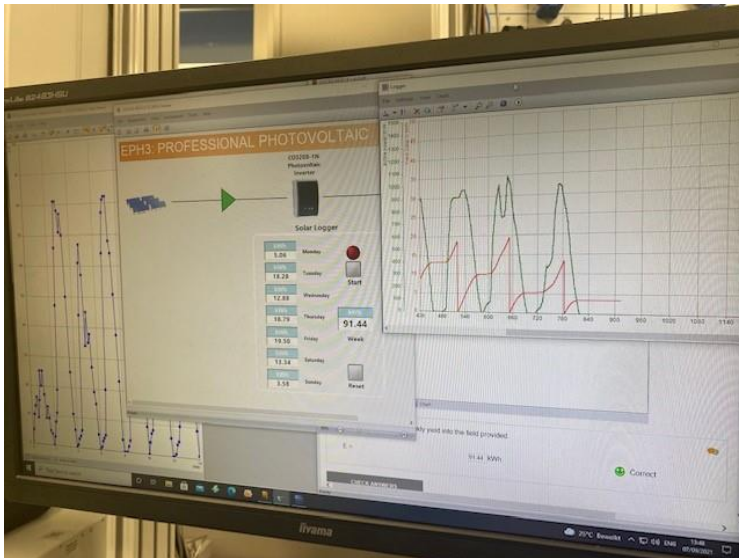
Image 3.1.7

Simulation made of the solar panels an inverter and the house.

What we learned from these experiments.

How the solar panel works with the amount of light that falls on it. How to place the solar panels this is around the angle of 36 degrees towards the east or west. The connection of solar panels, this depends on how many solar panels you have, but usually you go with a string of solar panels to your inverter. This is just a big loop that ends up with a plus and minus. There must also be an earth cable running to your installation.

How solar panels react with shade, they deliver much less here, so it is important that your solar panels do not end up in the shade too much or not at all.

And especially interesting how solar panels work together with the grid. when solar panels supply too little, the inverter will switch off immediately. If a lot of energy is generated, it is delivered to the house. And the rest of the energy to the grid.

So now a lot of energy is generated on a sunny day. But then not always a lot of energy is consumed. But this energy has to go somewhere, but it can't go into the grid because there is too little demand for energy. So the inverter will also switch off because no energy is needed. This will therefore happen much more often in the future, so a smart grid is applicable. And in the future many more smart houses and perhaps use of energy when it is widely available. These are nice topics that we can think about and also for the future.

3.2 Energy management

The SmartGrid project group have been working with the energy management tests. The main goal of these exercises was to understand how an inductive and capacitive load influences the whole energy system.

The main topics that the group has been working on were: the mains power voltage, balanced inductive and capacitive loads. The last two are meant to be done in order to see the actual effects of the two types of reactive power, inductive and capacitive, on an electrical network.

1. Measurement: Mains power voltage
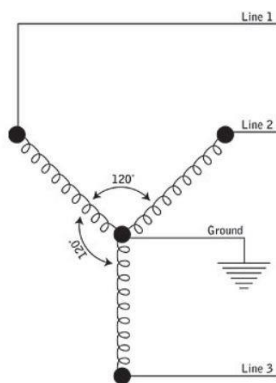
Image 3.2.1: Star Configuration of an Electrical Network

In the case of a star configuration of the network, each of the 3 lines voltages (phase-to-neutral) are equal, 230V for low-voltage networks, and their phase angles are 120° apart. The phase-to-phase voltages are also equal, but in this case it 400V for low-voltage networks.

In order to verify and confirm this, we set up the following experiment and took some measurements.
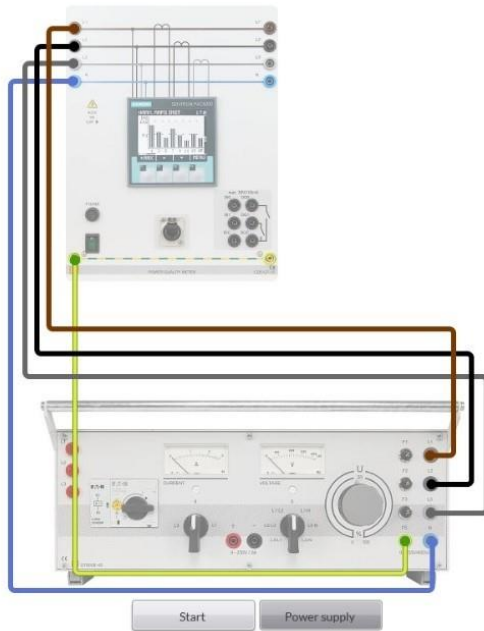
Image 3.2.2 Experiment for Measuring the Star Configuration Voltages

Voltages	Values
U_{1N}	229V
U_{2N}	231V
U_{3N}	230V
U_{12}	399V
U_{23}	401V
U_{13}	400V

Image 3.2.3: Star Configuration Measurements

From this experiment, it can be concluded that within a certain error margin, the mains voltage is indeed 230V phase-to-neutral and 400V phase-to-phase.

2. Measurement: Three-phase load connected in star configuration

In order to see the effects that the reactance has on the network, the following experiments have been created. Multiple of values of inductors and capacitors have been used, so that a better conclusion could be drawn.

To calculate the reactance, the following formulas have been used:

Inductive: $X_L = \frac{Q_L}{I_{1N}^2}$ $X_L = \frac{Q_L}{I_{1N}^2}$

Capacitive: $X_C = \frac{U_{1N}}{I_{1N}}$ $X_C = \frac{U_{1N}}{I_{1N}}$

2.1. Balanced inductive load
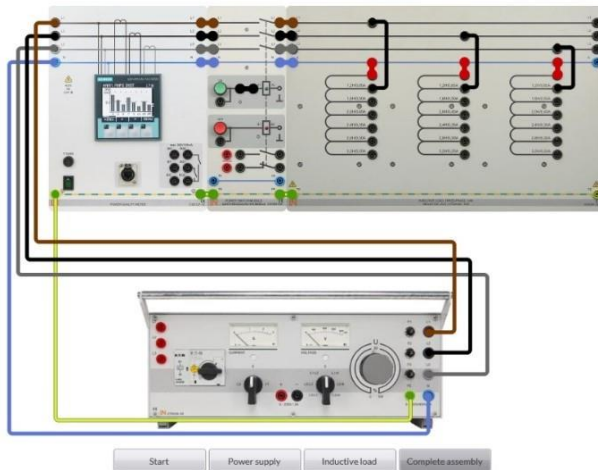
Image 3.2.4: Experiment for Measuring the Parameters of an Inductive Load

Measurement-1	Values
L	1.2H
U_{1N}	229V
U_{12}	395V
I_1	0.61A
P_1	15W
Q_1	139VAR
S_{12}	140VA
P_Σ	45W
Q_Σ	426VAR
S_Σ	429VA
$Cos(\varphi)_\Sigma$	0.12
X_L	374Ω

Image 3.2.5: Inductive Load of 1.2H Measurements

Measurement-2	Values
L	2H
U_{1N}	229V
U_{12}	395V

I_1	0.36A
P_1	8W
Q_1	82VAR
S_{12}	83VA
P_Σ	24W
Q_Σ	254VAR
S_Σ	256VA
$Cos(\varphi)_\Sigma$	0.10
X_L	633Ω

Image 3.2.6: Inductive Load of 2H Measurements

Measurement-3	Values
L	3.2H
U_{1N}	228V
U_{12}	395V
I_1	0.22A
P_1	4W
Q_1	51VAR
S_{12}	51VA
P_Σ	14W
Q_Σ	157VAR
S_Σ	158VA
$Cos(\varphi)_\Sigma$	0.10
X_L	1054Ω

Image 3.2.7: Inductive Load of 3.2H Measurements

From these measurements it can be observed the fact that with a higher inductance, the reactance of the circuit is increasing. The current that runs is becoming smaller and smaller which ultimately results in a smaller reactive power across the circuit. Another thing that can be observed is that the cos(φ) is also decreasing as the reactance becomes higher. In the end, the cos(φ) is closing to 0, as the reactance overcomes a lot the resistance of the circuit.

2.2. Balanced capacitive load
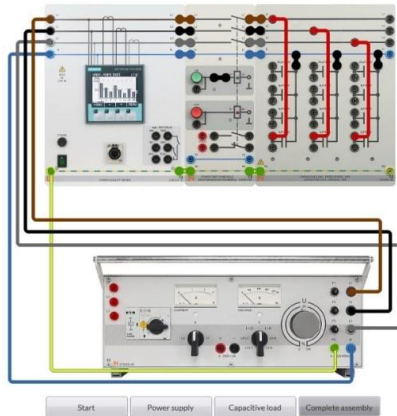
Image 3.2.8: Experiment for Measuring the Parameters of a Capacitive Load

Measurement	Value
C	$2\mu F$
U_{1N}	$229V$
U_{12}	$396V$
I_1	$0.15A$
P_1	$0W$
Q_1	$33VAR$
S_{12}	$34VA$
P_Σ	$0W$
Q_Σ	$99VAR$
S_Σ	$101VA$
$Cos(\varphi)_\Sigma$	0
X_C	1533Ω

Image 3.2.9: Capacitive Load of 2uF Measurements

Measurement	Value
C	$4\mu F$
U_{1N}	$229V$

U_{12}	396V
I_1	0.29A
P_1	0W
Q_1	66VAR
S_{12}	67VA
P_Σ	0W
Q_Σ	198VAR
S_Σ	201VA
$Cos(\varphi)_\Sigma$	0
X_C	787Ω

Image 3.2.10: Capacitive Load of 4uF Measurements

Measurement	Value
C	8μF
U_{1N}	229V
U_{12}	396V
I_1	0.59A
P_1	0W
Q_1	133VAR
S_{12}	136VA
P_Σ	0W
Q_Σ	400VAR
S_Σ	407VA
$Cos(\varphi)_\Sigma$	0
X_C	383Ω

Image 3.2.11: Capacitive Load of 8uF Measurements

From all these measurements, it can be clear observed that with a higher capacitance of the circuit, the overall capacitive reactance of the circuit drops. Although, as the current increases, so does the reactive power across the circuit and the Cos(φ) becomes almost 0 as the current is 90° out of phase with the voltage.

3.3 Busbar systems.

Our goal is to understand the impact what the Busbar is having with the athor elements like resistors and voltage sources. Later it is the case that we will be using this setup but only to connect the panels to eachother.

We start with the board itself. As you can see on the board there are two lines on the top part of the board. Those are the two busbars. There are also buttons on the busbar. Q1 is the isolator for the busbar 1 and Q2 is the Isolator for Q2. Q3 on the athor hand is a cirquit breaker and is more there for the safety and that you can not switch anything off while the circuitbreaker is on. The isolators 1 and 2 can't be on at the same time at the same panel. There is also a busbar coupler to connect the first and second busbar to eachother. In figure 2 there you can see the Scada interface of the busbar system. In that everything can be seen what is also seen in on the physical busbarsystem
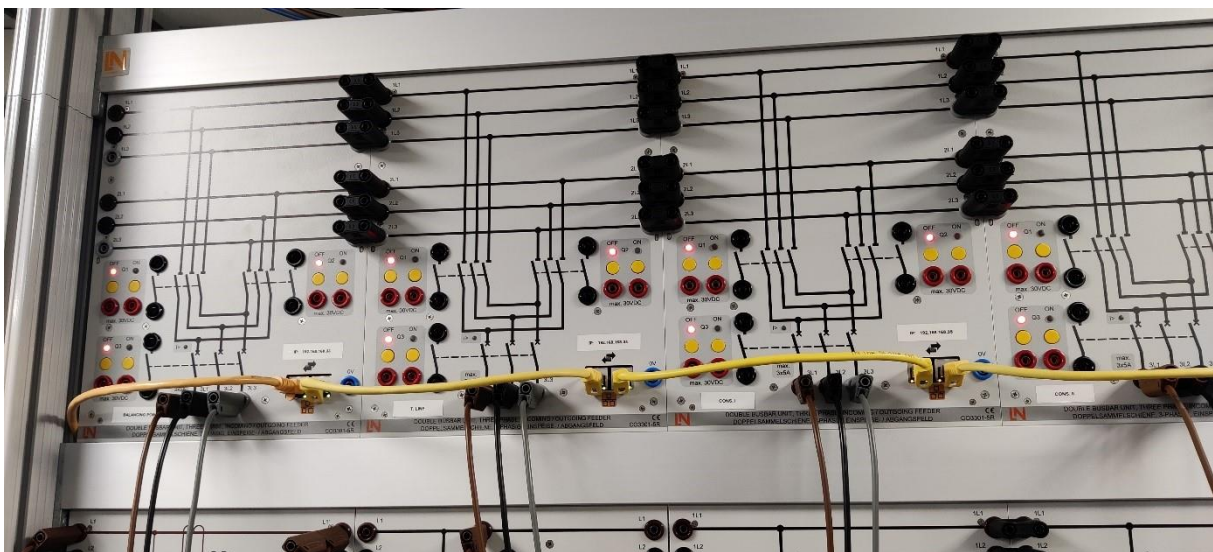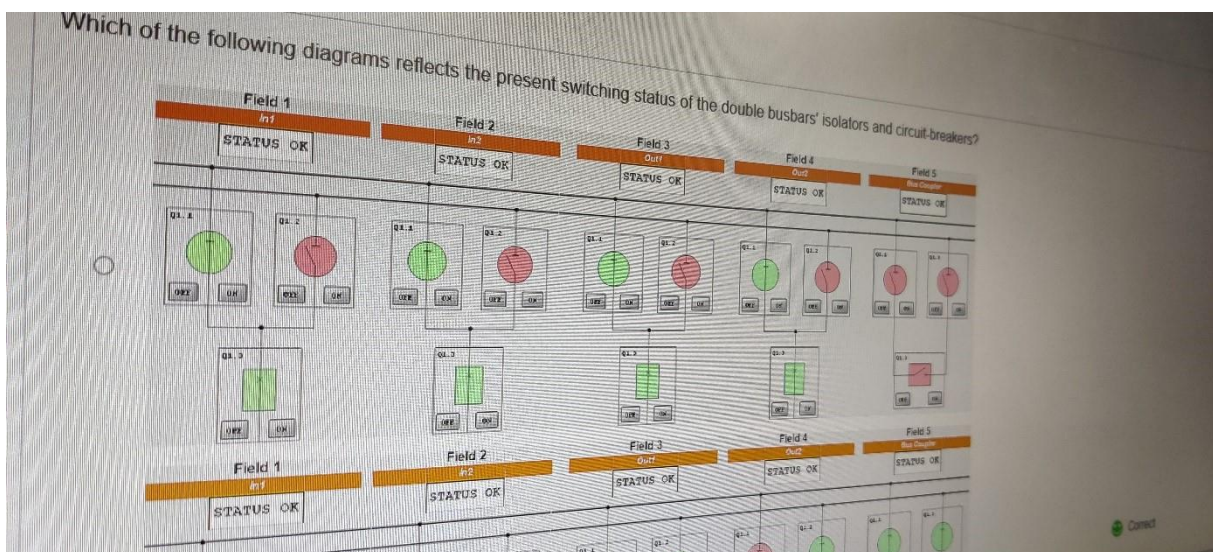

Image 3.3.1

Image 3.3.2

42

The scada interface itself has a bit more information and variables than figure 2 as can be seen in figure 3. So you can see for example that a transmission line is in use with this one as well as a coupler. The exercise with it is to discover how to use these features and what the effects of them are. One problem that will already

Image 3.3.3

That we concluded from this was that the transmission line has a loss of 8 to 10 wat. And the Busbar coupler has a loss of 3 to 5 watts.

What have we learned from this experiment

The busbar will play an important roll for the testing of the smartgrid. It will also be important because of from that every author component like the consumers and the generators.

One thing we have learned is the flexibility that comes with the busbar coupler and transmission line. Whilst until know there was no real need to use these too features, they can be good for simulating real life scenario's.

Furthermore we learned to work with the busbars because there can go something wrong with it pretty fast. Primarily it will go wrong when you do not use the right sequence to turn consumers or generators on and off. The sequence is for turning a consumer or generator on is turning on Q1 or Q2 and then turning on Q3.

3.4 Wind power

General view on wind power plant

A wind power plant's components which become apparent at first glance are
the **rotor**, **hub**, **machine housing** and **tower** which is mounted on a **foundation** embedded in the
ground. No **electric cables** are visible, indicating that the link to the power grid is situated
underground. The machine housing and tower are connected together via a **rotary mechanism**.

Tower & Foundation

The weight of up to 400 t exerted by the machine housing needs to be transmitted via the tower to
the foundation. Reaching a height of 170 m, the tower can have one of the following designs:

- Tubular steel

- Pylon

- Concrete post   (P.S. we would only use Tubular steel
  design)

Tower – Pod Connection

For a wind power plant to remain efficient, the rotor must always be aligned exactly against the
headwind. Because wind frequently changes direction, the pod to which the rotor is affixed has a
swivel mounting on the tower.

Rotor (blades)

The rotor on most wind power plants possesses three blades. These blades are subjected to
extraordinarily high loads :

- Bending moments caused by dead weight and wind force

- Irregular, cyclical loads caused by wind turbulence

- Fatigue caused by weathering

- High centrifugal forces

Lightning protection

All large wind power plants inevitably suffer lightning strikes. Without a lightning
protection system, the wind power plant would not have survived all these strikes. A lightning
protection system has become a standard feature for all new rotor blades.

Rotor blade mounting

The rotor blades and shaft are connected together via the hub, which also contains the blade
bearings and blade angle adjustment mechanism on wind power plants furnished with such a
mechanism.

Generator

The machine housing contains the generator needed for producing electrical energy. The machine
housing also contains additional equipment such as electronic controllers, hydraulic systems as well
as optional features such as gears, brakes, and cooling units (fans).

Wind Power Plan Concepts
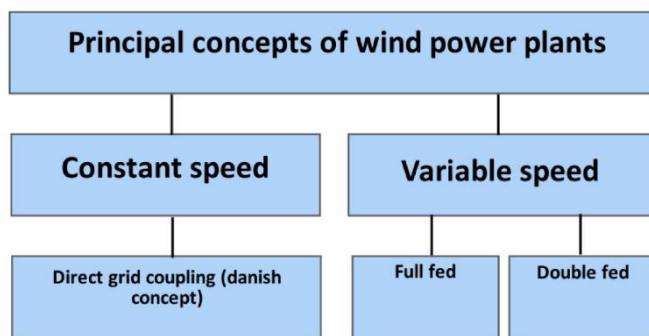
Image 3.3.4

Though each wind power plant is designed and optimized according to the conditions prevailing at its installation site, the plant nonetheless fits into one of three main concepts:

Constant-speed wind power plant.

Danish concept.

- Asynchronous generators connected directly to the power supply

- The squirrel-cage, asynchronous generators forming part of such systems require little maintenance

- Are relatively economical.

- Do not require complex vane pitch control.

Constant-speed control

- the rotor vanes **usually** have a fixed pitch

- the (**asynchronous**) generator driven by the rotor is coupled directly with the power grid.

In the case of a constant-speed wind power plant, the frequency of the current supplied by the generator depends directly on the rotor speed. If adverse wind conditions prevent the wind power plant from maintaining this frequency, the network is decoupled. Once the rated frequency can be delivered again, the wind power plant is re-connected "softly" to the network, e.g., via a thyristor controller which acts like a dimmer and prevents undesired surges during circuit entry.

Variable-speed wind power plant

Dynamic loads can only be reduced by means of a variable speed range for the rotor in relation to the grid frequency. This can only be achieved by means of a variable-speed generator in conjunction with a frequency converter. Such systems can be produced using synchronous or asynchronous generators. Referring to our table, two cases will be discussed.

Synchronous generator with full feed
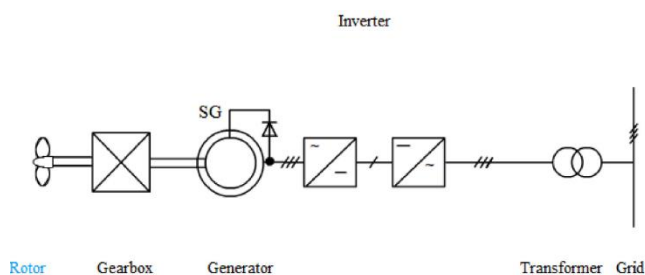
Image 3.3.5

- frequency converter with a DC link

- the variable-frequency alternating current produced by the generator is rectified before being fed via an inverter to the power grid.

Asynchronous generator with double feed

Variable-speed operation of a wind power plant

- The machine's slip power is fed into the power grid, and back from the power grid to the rotor. (This enables the machine to operate in the "generator/motor" modes)

- The frequency supplied by the converter is superimposed on the rotor field's frequency.

- The superimposed frequency remains constant, irrespective of the rotor speed.

- The speed range is determined by the frequency supplied to the rotor.

This concept poses very elaborate control requirements.
Special advantage of this concept - the ability to **separately** **control the active and reactive power**. Furthermore, just 1/3 of the generator's rated power is transmitted via the rotor circuit and frequency converter.

Control

Image 3.3.6

Both under partial load and full load, the rotor blades' angle can be adjusted by means of a special mechanism in accordance with wind speed and generator power, and thereby aligned nearly ideally into the wind.
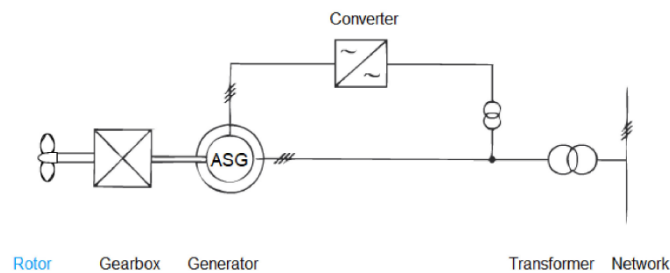This kind of mechanism is referred to as pitch control.

Slip control
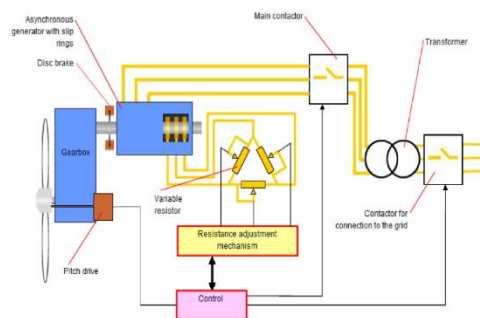
Image 3.3.7

Speed control
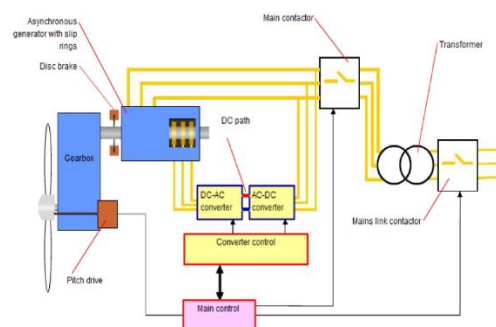
Image 3.3.8

Operation of a doubly fed induction generator

Function of a doubly fed induction generator
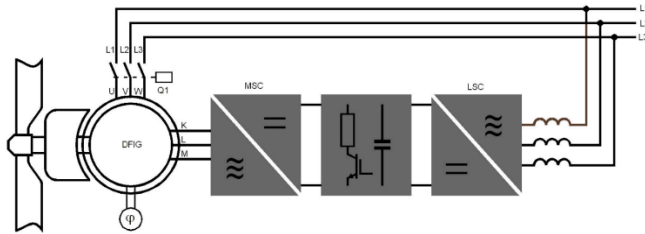
Image 3.3.9

- The generator's stator is connected via a power contactor to the grid.

- The generator's rotor is fed via an inverter.

- The generator must produce voltage of a constant frequency and amplitude in order to feed energy into the grid.

- This is achieved through proficient regulation of the current supply for the rotor.

Experiments

Influence of mechanical speed on generator voltage

Goals

- Understanding the relationship between a generator's frequency and speed.

Exercises

- Determining the generator voltage's frequency at 1200 rpm, 1300 rpm and 1400 rpm.

Results

	mechanical frequency [Hz]	voltage frequency [Hz]
1200 rpm	40	40
1300 rpm	43	43
1400 rpm	47	47

The generator behaves like a synchronous generator.

Influence of variable rotor frequency

Goals

- Understanding the relationship between generator speed, rotor current frequency and stator frequency.

Exercises

- Determining the feed frequency required by the rotor to raise the voltage frequency of the generator's stator to 50 Hz at a speed of 1200 rpm. Repeating this measurement at 1300 rpm and 1400 rpm.

Results

To achieve a stator frequency of 50 Hz:

- mechanical speed of 1200 rpm -- rotor voltage's frequency = 10

- mechanical speed of 1300 rpm -- rotor voltage's frequency = 7

- mechanical speed of 1400 rpm -- rotor voltage's frequency = 3

1) At variable speed , the stator frequency can be held constant by adjusting the rotor frequency.

2) At constant speed, the stator frequency can be varied via the rotor frequency.

3) The stator frequency is determined by adding the rotor frequency and mechanical speed.

Influence of rotor current

Goals

- Understanding the relationship between rotor current and stator voltage.

Exercises

- Determining the influence of rotor current on stator voltage.

- Investigating the influence of speed and current.

Results
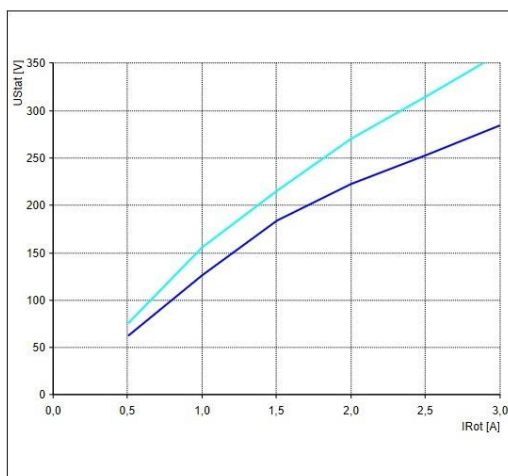
Image 3.3.10

Part 1

What does the obtained diagram indicate?

1. Increasing the rotor frequency at constant amperage also increases the stator voltage.

2. Increasing the rotor current also increases the stator voltage.

What causes the change in the output voltage at constant current and variable rotor frequency?

The mechanical rotor speed and rotor current frequency undergo addition, thereby increasing the speed of the rotor's magnetic field and raising the stator voltage.

Part 2

Now:

-   SPEED CONTROL mode is on

-   speed is 1200 rpm

-   frequency is 0 Hz.

	n [rpm]	1200	1250	1300	1350	1400
1A	U [V]	120	125	130	134	135
2A	U [V]	225	235	240	250	260
3A	U [V]	288	305	320	330	345
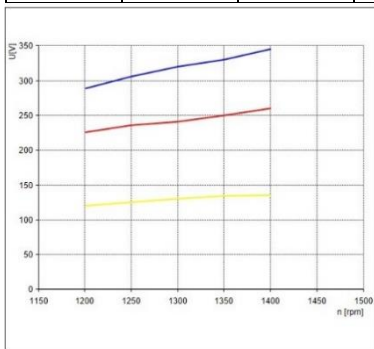
Image 3.3.11

What does the obtained diagram indicate?

1. A change in rotor current from 2A to 3A increases the stator voltage to a lesser extent than a change from 1A to 2A. This is due to the generator's saturation effect.

2. Increasing the speed at a constant rotor current increases the stator voltage.

3. Increasing the rotor current proportionally increases the stator voltage.

Grid synchronization for a DFIG

Goals

- Synchronizing the generator with the grid

- Understanding the influence of rotor current and frequency

- Synchronizing the generator automatically.

The following conditions must be met to connect the generator to the grid:

- Grid frequency = generator frequency

- Grid voltage = generator voltage

- Grid phase angle = generator phase angle

NB! If a large-scale plant fails to meet any of these conditions, connecting the generator to the grid results in high compensation currents which can damage individual plant components. In the case of our experimental plant, connection can only take place within a window monitored by software. Connection commands issued outside the window are ignored.

Exercises

- Setting the rotor current and frequency so that the generator can be connected to the grid

- Performing grid synchronization at various speeds

- Letting the generator automatically synchronize with grid parameters

Results

How can the phase shift between the power grid and generator be adjusted?

If the generator and grid frequencies are similar, a phase shift occurs between the generator and grid. In this case, the phase angle can be adjusted through minor changes in the generator frequency.

How does the rotor current influence synchronization with the grid?

The rotor current influences the generator voltage's magnitude.

Generator voltage in synchronized mode
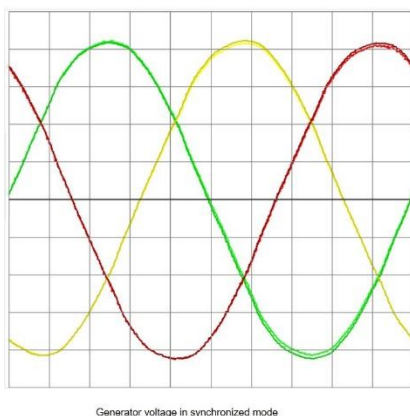
Image 3.3.12

Compare the generator voltages in the offline and online modes:

1. When the generator is online, it's voltage is equal to the grid voltage

2. When the generator is offline, the voltages differ in terms of amplitude, frequency, and phase angle

3. The ripple in the generator's voltage is caused by the rotor current control mechanism

Observe the generator voltage:

1. As the speed changes, the generator voltage, frequency, and phase angle are regulated to achieve synchronisation with the grid.

Chapter 4 concept design

The design process

The project will be structured by applying the PIT-stop model. PIT means Project, Innovation and Team. This is a project management method used in projects that electrical engineers work on. Both disciplines use their own design methodology and use PIT-Stop for the entire/joint design process.

As described earlier, PIT stands for Project, Innovation and Team. The Dutch book Designing technical innovations (Oskam, 2017) contains a detailed overview of this method, including all kinds of tools per phase. Typical is the distinction that is always made between:

1. Determine whether adjustments to the project plan and planning are necessary or whether one or more activities have to be repeated (Project);

2. Evaluate the end result of a phase that has just been completed and discuss whether this fits with the original goal and requirements (Innovation);

3. Check whether the team works well together and consists of the right people to enter the next phase (Team). Due to the neutral approach of this method, it is possible to synchronize between different specific methodologies.

The 5 phases of the PIT-stop model are:

I. Orientation

II. Analysis

III. Concept Design

IV. Detailed Design

V. Realization

4.1 Concept Design (IPS)

4.1.1 Objective Concept design

We aim to complete this project successfully. We want to comply with the project description, we will simulate this in the power lab of building r29. Here are several Lucas Nuelle panels. With the energy systems we need.

We as ips will ensure that the energy systems that supply and consume energy will be properly connected to the busbars and the grid. Here we are going to use the solar panels, the battery, the wind turbine, and two different consumers. For ese, the aim is to keep the balancing point at 0 so that you do not return power in Watts or demand from the grid.

We will research this in the beginning with different tests and we will store the values of these tests so that we can make the best choices and start using this system and finally submit it to use also in the project of the Kleefse waard.

4.1.2 Global input-process-output scheme

In the Input Output report we discuss all the inputs and outputs we receive from the Smart grid, and we look at how we are going to process these inputs and outputs and what the response should be to this input. In this way we can create a global picture of how the esers should react.
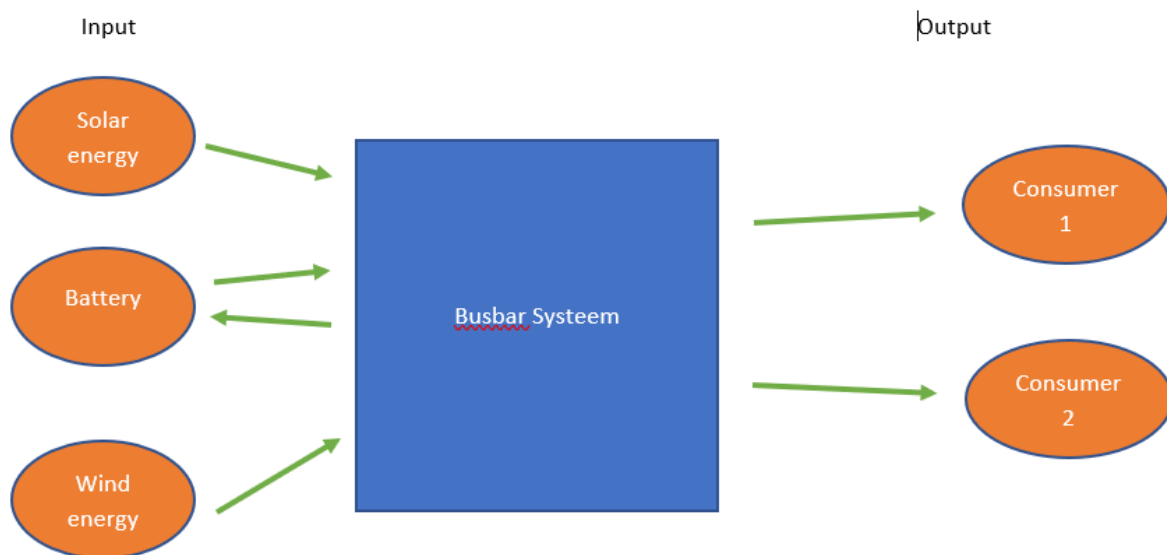

Image 4.1.1

The inputs are solar energy, battery and wind energy. Which are connected to the busbar system. There are also 2 outputs on consumer. Here, for example, you should think of your house.

The battery can also be used as output, hence the arrow back because you can also charge the battery when more energy comes in than goes out.

4.1.3 hierarchical model
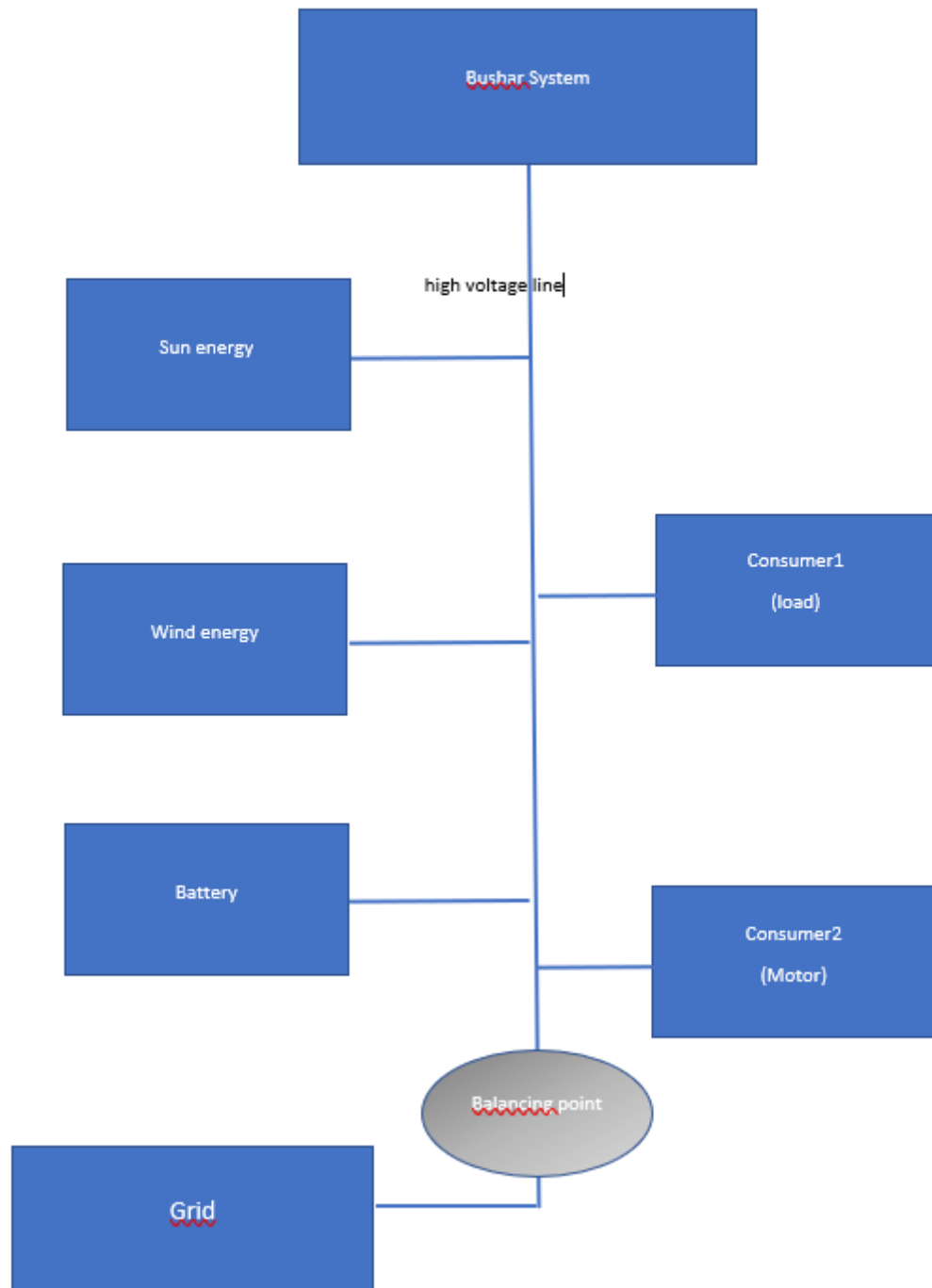
Image 4.1.2

4.1.4 component values
Batterij:

Energy storage system

Available battery capacity	2 kWh
Inverter's rated power	1.5 kW
Inverter's maximum efficiency	96%
Battery working life:	designed for 20 year life span
Battery cell chemical constituents:	lithium-iron phosphate
Charge cycles:	> 10,000
Battery voltage:	51.2 V_{DC}
7" Multi-touch display	
Port: Ethernet	
Active-power control per SCADA	
Integrated web server	
Output voltage:	3x400V / 50Hz

Image 4.1.3

Storage system terminal panel

Grid connection:	three-phase, 3x400V
2 power meters	
3-phase terminals for PV system and loads	
3x B6A automatic circuit breakers for storage system	
3x B6A automatic circuit breakers for wattmeter	
Connections via 4 mm safety jacks	

Image 4.1.4

Sonnen makes home batteries that can store homemade energy from solar panels and use them smartly. In regular homes, 30 to 55 percent of the generated electricity can be used for own use, while with a storage device such as sonnen, this increases to 60 to no less than 80 percent.

That's because those storage devices can store and use the energy generated during peak times (at midday) when there are peak usage (especially morning and evening). For example, you as a family have to purchase less electricity from the grid and you save a lot on your energy bill.

Inverter StecaGrid 3203

DC input side (PV generator)	
Maximum input voltage	1000 V
Operating input voltage range	250 V … 800 V
Number of MPP tracker	1
Maximum input current	11.0 A
Maximum short circuit current	+20 A / -13 A
Maximum input power at maximum active output power	3300 W
Maximum recommended PV power	

Image 4.1.5

AC output side (Grid connection)	
Grid voltage	320 V … 480 V (depending on regional settings)
Rated grid voltage	400 V
Maximum output current	7.0 A
Maximum active power (cos phi = 1)	3200 W
Maximum active power (cos phi = 0.95)	3040 W
Maximum active power (cos phi = 0.9)	2880 W
Maximum apparent power (cos phi = 0.95)	3200 VA
Maximum apparent power (cos phi = 0.9)	3200 VA
Rated power	3200 W
Rated frequency	50 Hz and 60 Hz
Frequency	45 Hz … 65 Hz (depending on regional settings)
Night-time power loss	< 3 W
Feeding phases	three-phase
Total harmonic distortion (cos phi = 1)	< 1 %
Power factor cos phi	0.8 capacitive … 0.8 inductive

Image 4.1.6

Characterisation of the operating performance	
Max. efficiency	98.6 %
European efficiency	97.9 %
Californian efficiency	98.3 %
MPP efficiency	> 99.8 % (static), > 99 % (dynamic)
Own consumption	< 8 W
Power derating at full power from	50 °C (T_{amb})

Image 4.1.7

Motor

Three-phase asynchronous motor, squirrel-cage, 1 kW,, 690/400 V

Three-phase asynchronous machine industrial model with pronounced pull-out torque

- Nominal power: 1.1 kW
- IE3, η: 84,4 %
- Nominal speed: 1445 rpm
- Nominal voltage: 690/400, 50 Hz
- Nominal current: 1.45/2.55 A
- cos phi: 0.75
- Provision of motor data by means of electronic nameplate EDD (Electronic Drive Data)
- Dimensions: 380 x 220 x 250 mm (HxWxD)
- Weight: 19 kg

Image 4.1.8

Three-phase multi-function machine, 1.0 kW

Functions:

- Three-phase asynchronous motor with slip-rings
- synchronous machine

Data:

- Nominal voltage: 400/230 V, 50 Hz
- Nominal current: 2.0A / 3.5 A
- Nominal speed: 1400 / 1500 rpm
- Nominal power: 0.8 kW
- cos phi: 0.75
- Exciter voltage: 130 V AC / 24 V DC
- Exciter current: 4 A AC / 11 A DC
- Dimensions: 500 x 220 x 250 mm (BxHxD)
- Weight: 20 kg

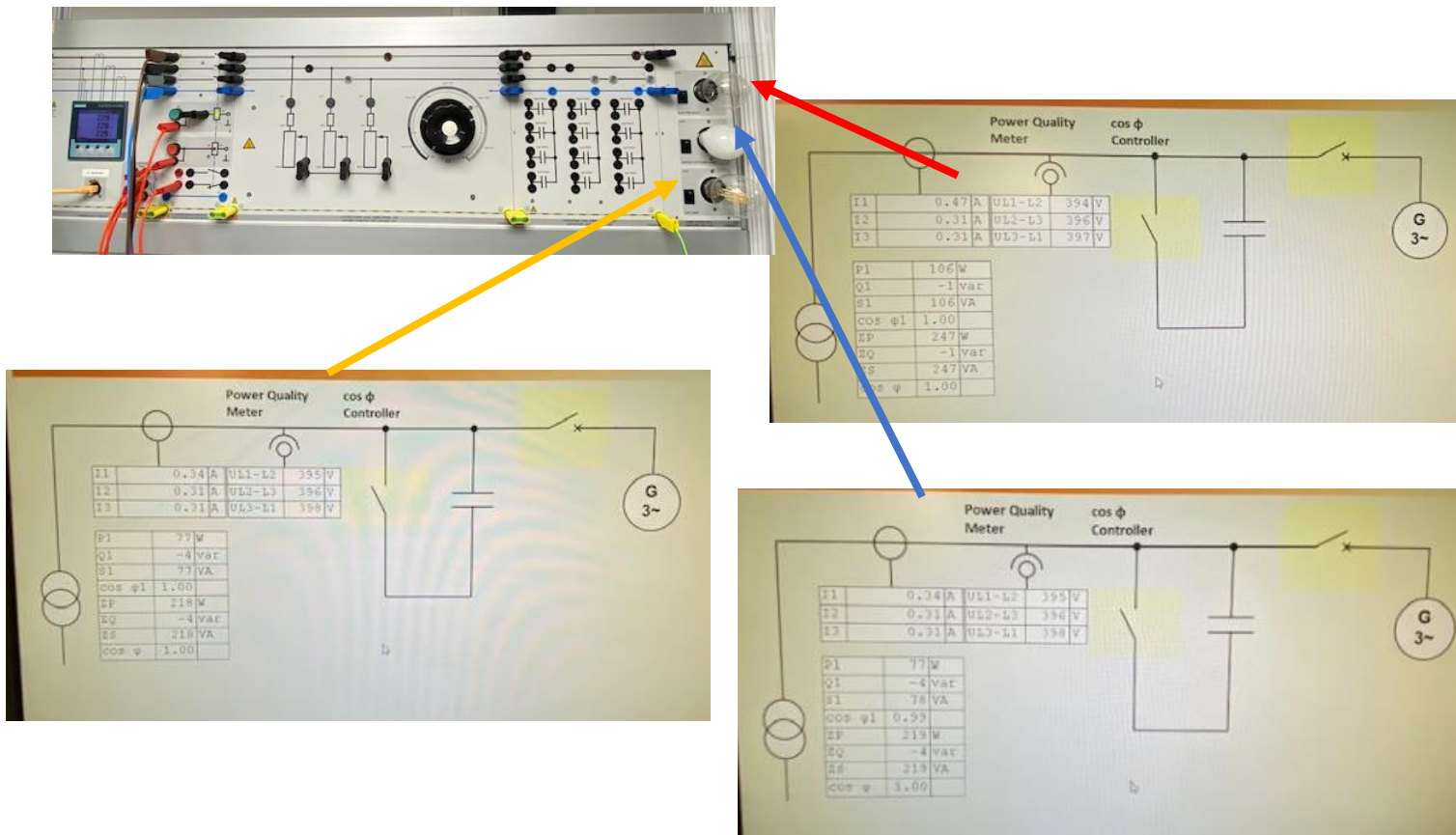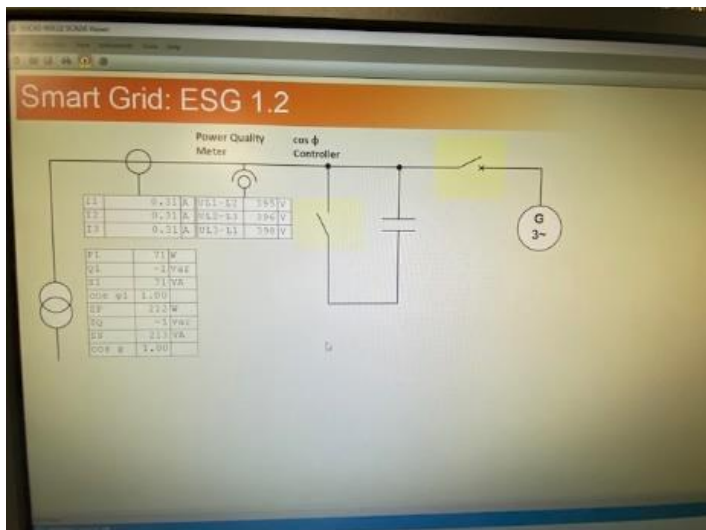*Image 4.1.9*

4.1.5 measured values during simulation:

Power Quality Meter / cos φ Controller

I1	0.47 A	UL1-L2	394 V
I2	0.31 A	UL2-L3	396 V
I3	0.31 A	UL3-L1	397 V
P1	106 W		
Q1	-1 var		
S1	106 VA		
cos φ1	1.00		
ΣP	247 W		
ΣQ	-1 var		
ΣS	247 VA		
cos φ	1.00		

Power Quality Meter / cos φ Controller

I1	0.34 A	UL1-L2	395 V
I2	0.31 A	UL2-L3	396 V
I3	0.31 A	UL3-L1	398 V
P1	77 W		
Q1	-4 var		
S1	77 VA		
cos φ1	1.00		
ΣP	218 W		
ΣQ	-4 var		
ΣS	218 VA		
cos φ	1.00		

Power Quality Meter / cos φ Controller

I1	0.34 A	UL1-L2	395 V
I2	0.31 A	UL2-L3	396 V
I3	0.31 A	UL3-L1	398 V
P1	77 W		
Q1	-4 var		
S1	78 VA		
cos φ1	0.99		
ΣP	219 W		
ΣQ	-4 var		
ΣS	219 VA		
cos φ	1.00		

Image 4.1.10

Lights off

Smart Grid: ESG 1.2

Power Quality Meter / cos φ Controller

I1	0.31 A	UL1-L2	395 V
I2	0.31 A	UL2-L3	396 V
I3	0.31 A	UL3-L1	398 V
P1	71 W		
Q1	-1 var		
S1	71 VA		
cos φ1	1.00		
ΣP	222 W		
ΣQ	-1 var		
ΣS	213 VA		
cos φ	1.00		

Lights on all

Smart Grid: ESG 1.2

Power Quality Meter / cos φ Controller

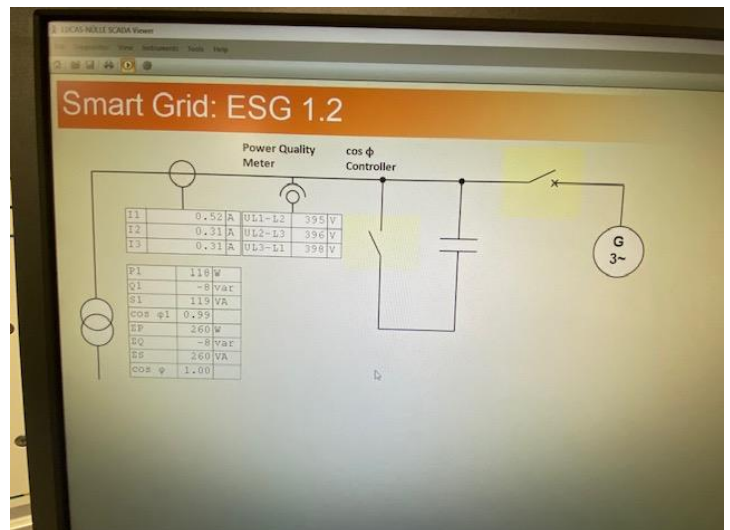| I1 | 0.52 A | UL1-L2 | 395 V |
I2	0.31 A	UL2-L3	396 V
I3	0.31 A	UL3-L1	398 V
P1	118 W		
Q1	-8 var		
S1	119 VA		
cos φ1	0.99		
ΣP	260 W		
ΣQ	-8 var		
ΣS	260 VA		
cos φ	1.00		

Image 4.1.11

This is from load 2 note that it is an almost constant value here but in real life this is not the case and that what happens is not to be expected.

Load two when we only run the motor the resistors and lamps above are disconnected.

Engine at load 2

Star switched

without load

RPM	Nm	watt	Stroom
2600	3.05	1151	
2700	2.65	966	
2800	1.90	686	1.06 A
2850	1.45	540	0.82 A
2900	0.90	385	0.6 A
2950	0.4	227	
3000	-0.4	25	
3050	-1.35	-19	

with load

RPM	Nm	watt	Stroom
2600			
2700			
2800	1.88	882	1.33 A
2850	1.45	737	1.10 A
2900	0.9	577	0.86
3050			

From these measurements you can conclude that the load constantly takes 0.3 amps apart from the motor. If it is set to 750 ohms, when we make the load smaller, the resistance is smaller, so the current will increase i=u/r

Load 1 has a maximum value of +-260 watts in star connection

Load 1 in delta is +-784 watts
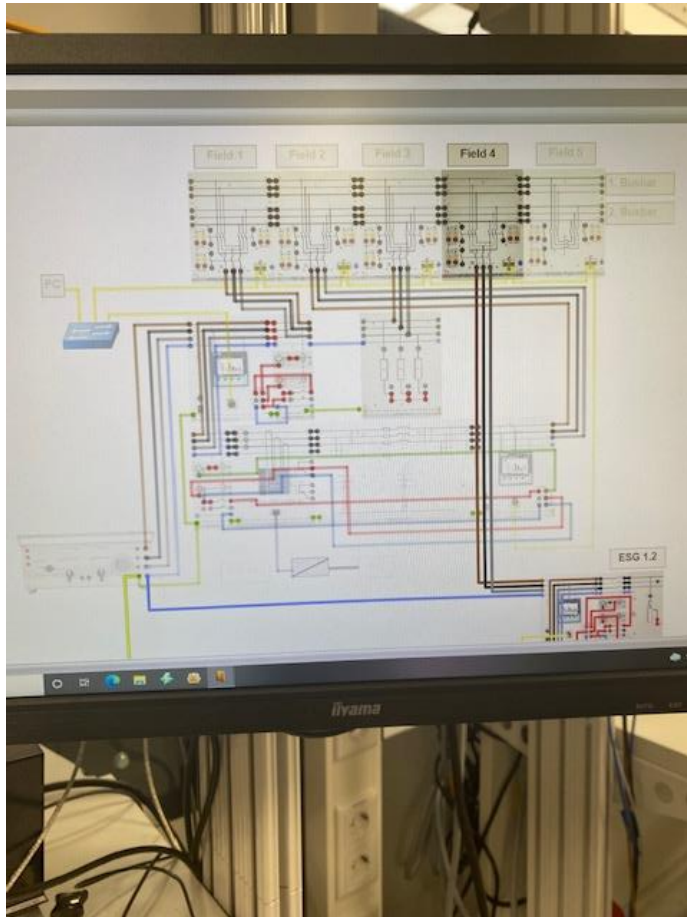
Different testings

Basic setup

Image 4.1.12

Line of 300 kilometers is the volt loss: 39 current is 0.9

Line of 150 kilometers the voltage drop is 12 volts with 0.9 amps.

Source directly connected to the motor the resistors through the 150 kilometer line

0.4 amps to the resistors . 0.6 to the engine. Difference in the line of 150 kilometers is 0.2 volts
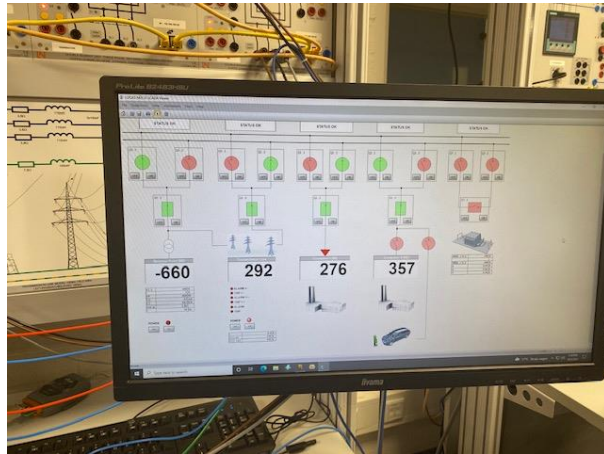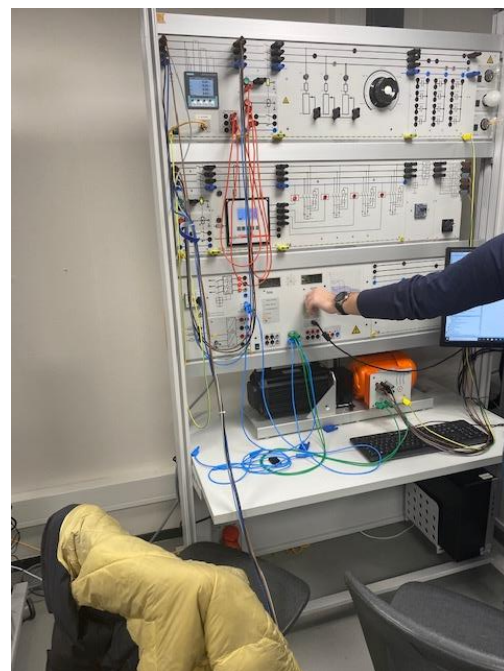

Image 4.1.13

Image 4.1.14

Image 4.1.15

The engine is a load on the grid. With the engine we can adjust the torque so that the engine becomes heavier and therefore requires more from us.

When you use the coupler and turn on the source and the transmission line only the source is used because the current chooses the easiest path across the transmission line more resistance is used.
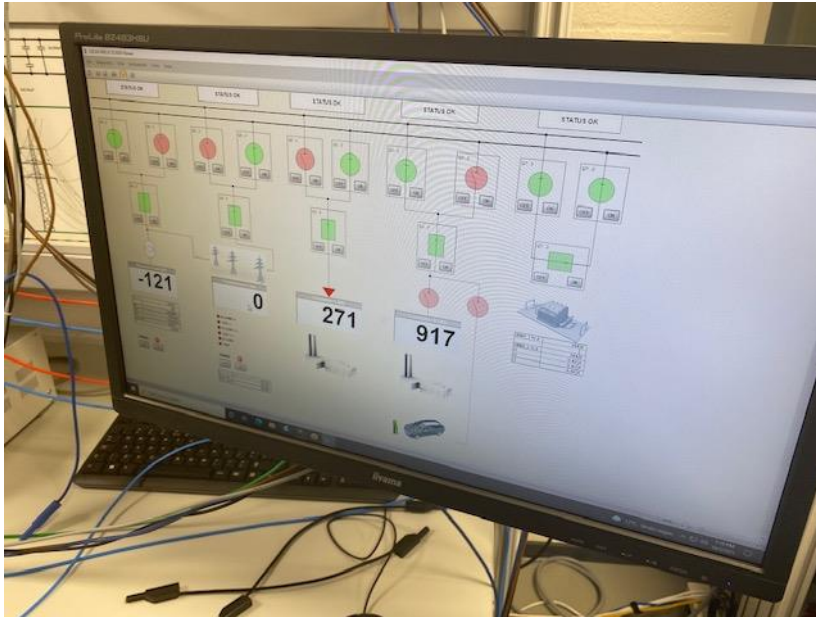

Image 4.1.16

When you only use the source along with the coupler, the loss is 6 watts

When you only use the transmission line (150 kilometers) together with the coupler, the loss is 79 watts

So you can conclude from this that only the source is better.
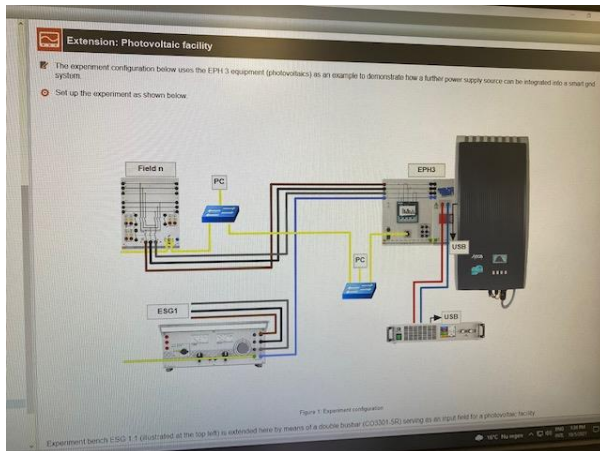
Smart grid extentions.

Photovoltaic   Windpower
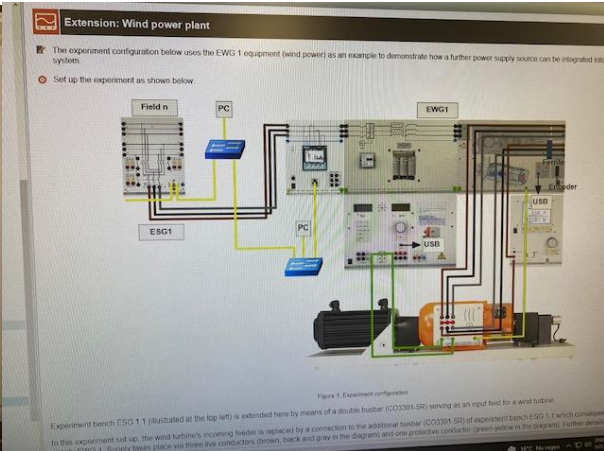
Image 4.1.17

Image 4.1.18

Battery storage   Synchronous generator

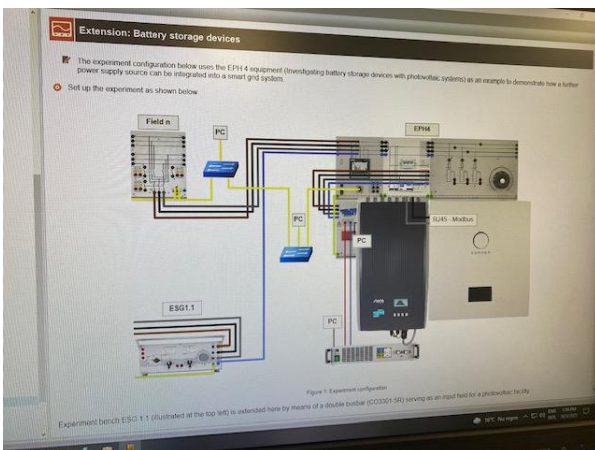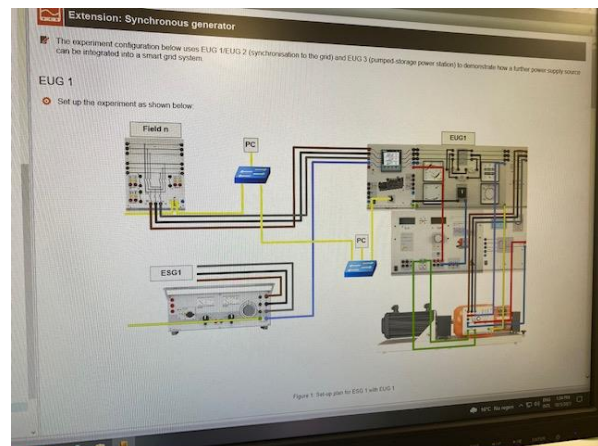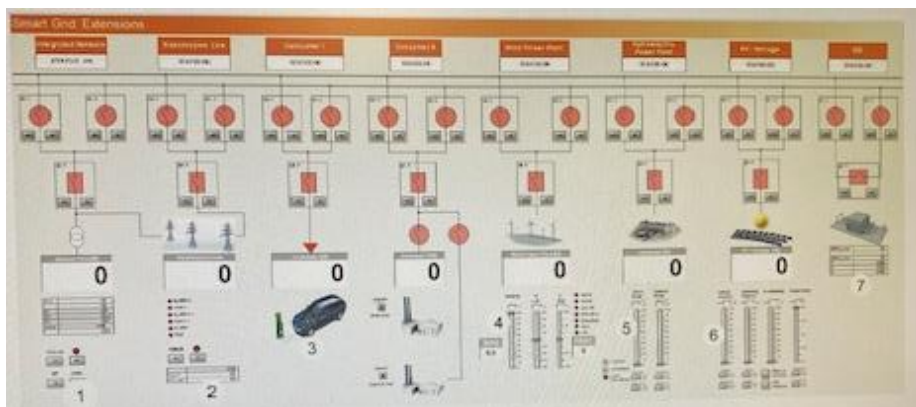*Image 4.1.19*

Image 4.1.20

Image 4.1.21

Now we are going to use the PV installation, wind energy, battery where we can store energy

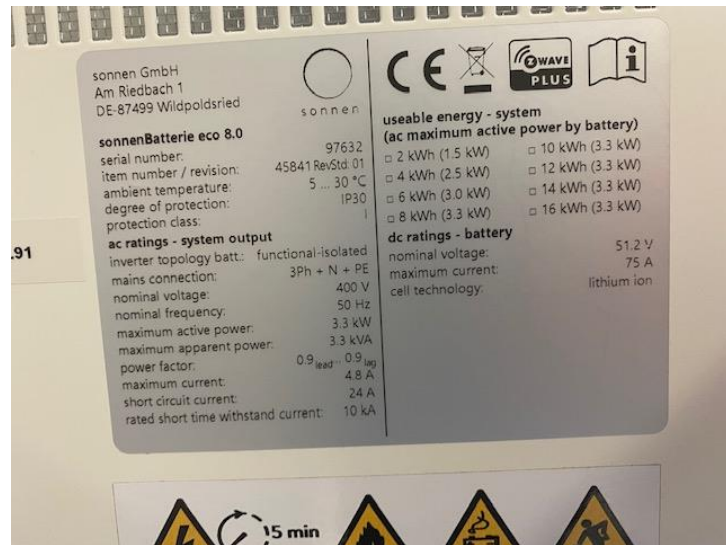The battery where we will store the energy

Image 4.1.22

Image 4.1.23

The inverter that will convert the generated dc
voltage into ac (three phases).

Image 4.1.23
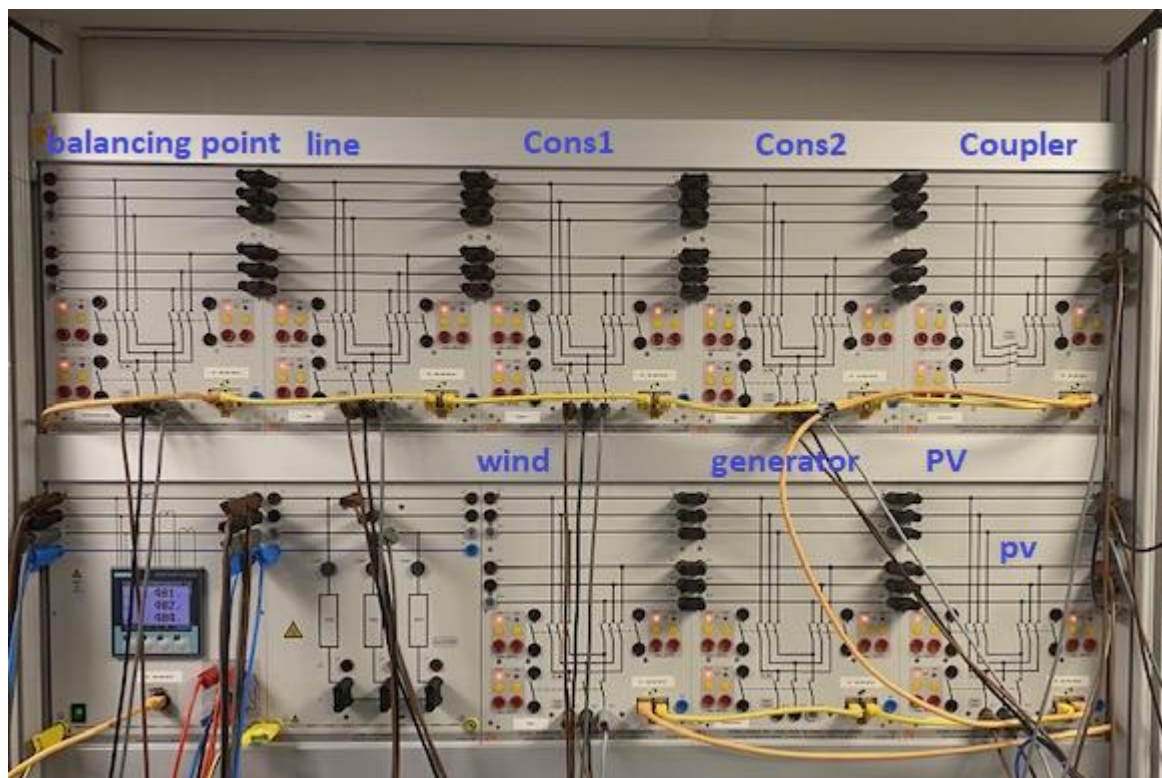
Image 4.1.24

We are going to play a time schedule on the PV installation and the wind power. Different values that come in a day but in a shorter time. Then we don't have to sit for a day 😊. This way we can see what is happening via scada. The task for ese will soon be to keep the supply and demand of energy equal.

The battery is charged when the PV installation and the wind energy exceeds the energy demanded by consumers one and two. The battery would be discharged if the PV installation and the wind power yield too little to meet the demand of consumers.

A positive number means that the energy is being consumed. When there is a – sign in front of the number, the energy is supplied.
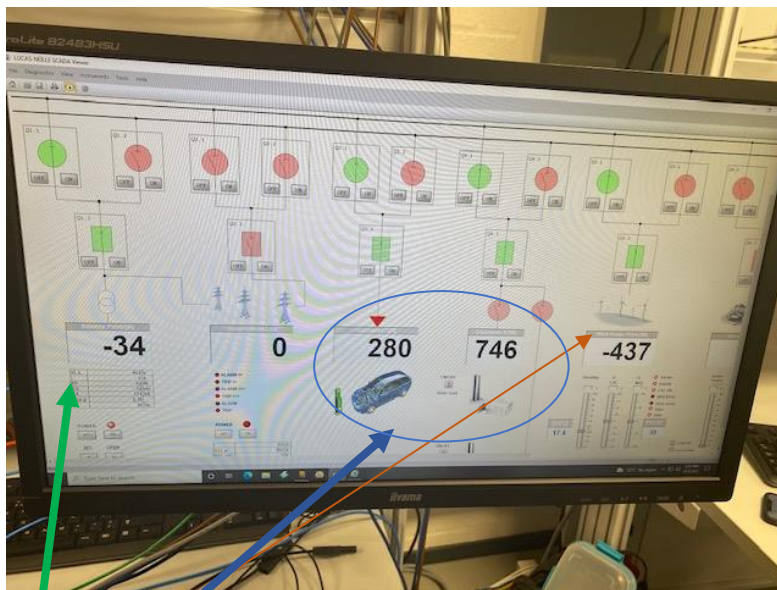
Image 4.1.23

The wind supplies energy to the grid as you can see from the minus sign.

The consumers consume energy here is not a minus sign

Balancing point is now -34 so delivered here but it is not possible to store energy in the lines. So the intention is that the balancing point remains equal to 0. So supply and demand must be equal, so this is our goal to regulate.

Problemen die we nu zijn tegengekomen.

- Nog niet gebruik gemaakt van de generator.

- Het balancing point gaat heel snel van opnemen naar leveren en weer terug.

- De batterij kan opnemen en afgeven maar dit schakelen duurt heel lang.

- Transmissie lijn heeft een best groot verlies.

Scada file

Balance point

- The smart grid can be connected or disconnected by pressing the power on or off

- Set SG: connects all the busbars of the smart grid at the same time

- Open ALL: disconnects all the busbars of the smart grid at the same time.

Image 4.1.26

Transmission line

- The transmission line can be connected or disconnected by pressing the power on or off.

- Alarm1> over current

- Alarm I>: Over current I> detected.

- Trip I>: Over current I> stage was activated. The power switch CO3301-5P will be opened.
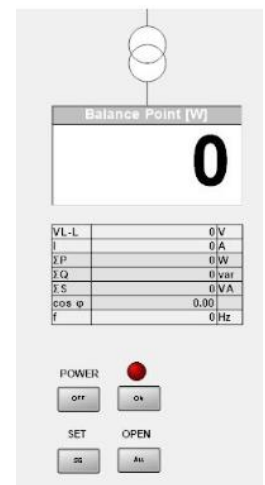
- Alarm I>>: Short circuit stage I>> detected.

- Trip I>>: Short circuit stage I>> was activated.

- Alarm: Over current I> or short circuit stage I>> detected.

- Trip: Over current I> or short circuit stage I>> was activated.
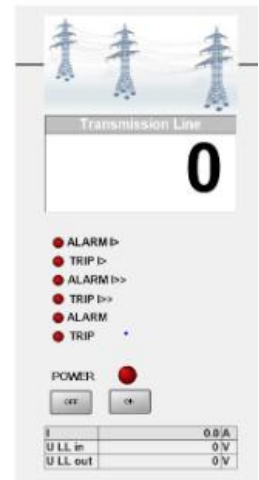
Image 4.1.27

Wind power

- Wind Power Plant [W]: Display of the consumed or supplied active power.

- [m/s]: Display of the wind speed.

- Pitch °: Display of the Pitch angle.

- Derating (%): Setting of the active power derating in % (0% means no power limitation. 100% means full power limitation = no active power is fed into the grid.)

- Q LSC (%): Reactive power feed in or consumption of the LSCs (Line Side Converter)

- Q MSC (%): Reactive power feed in or consumption of the MSCs (Machine Side Converter)

Generator

- Generator [W]: Display of the consumed or supplied active power.

- STARTUP: starts the machinery, synchronizes it and feeds or consumes power in accordance with the settings.

- SHUTDOWN: reduces the machinery power to zero, stops synchronization and shuts down the machine.

- LOAD FOLLOWING: Automatic load sequence operation.the power P/Q is measured at the balance node with the generator compensated.

- Active Power: Manual control of the active power. P/Q is regulated as a percentage of S/VA. That means that at 800 VA, you can supply or consume power P of -800 W to 800 W. The direction in which this takes effect can be modified by means of the buttons "Storing" and "Supplying".
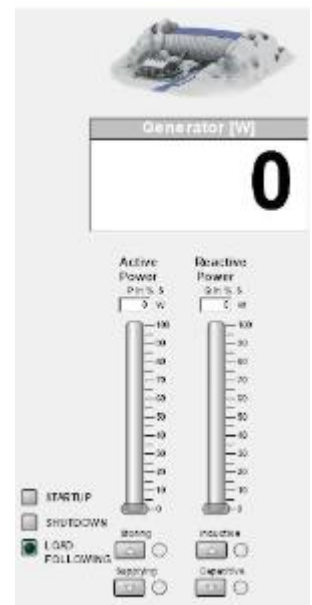
Image 4.1.28

- Reactive Power: Reactive power is adjusted in the same way, with the type of reactive power being specified by "Inductive/Under-Excited" and "Capacitive/Over-Excited" tor

Pv/Batterij

- PV/Storage [W]: display of the supplied or consumed active power

- Manual Control: Manual battery control

    o Charge: Charging the battery storage

    o Discharge: Discharging the battery storage

- Operating reserve: Specification of the control power for the complete house system. (Consumers, generation with the photovoltaic panel and battery storage system). Depending on the system state, the specified power cannot be made available.

    o Positive: Power consumption of the house connection (Regulation by battery storage system)

    o Negative: Power fed into the grid from the house connection (Regulation by battery storage system)

Image 4.1.29

- PV Derating: Power limitation of the photovoltaic system power as a percentage of the nominal power.

- Power Factor: Provision of reactive power of the photovoltaic system (capacitive or inductive)

Testing battery

Acties

Alles sliders op 0: batterij charge 564 watt(production-consumption) production 677(wat er aan zon gemaakt word) consumption 107(wat er aan load gebruikt wordt)

Alles sliders op 0 behalve operating reserve 25% in positive mode: batterij charge 950 watt(production-consumption) production 676(wat er aan zon gemaakt word) consumption 104(wat er aan load gebruikt wordt)
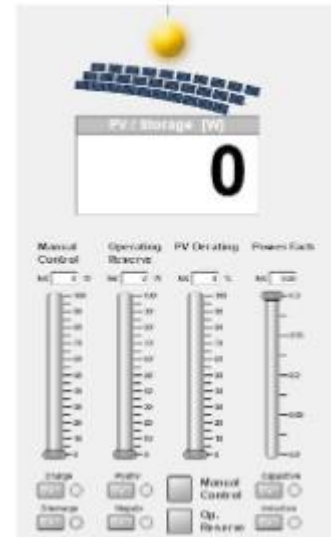
Alles sliders op 0 behalve operating reserve 50% in positive mode: batterij charge 1390 watt(production-consumption) production 677(wat er aan zon gemaakt word) consumption 106(wat er aan load gebruikt wordt)

Alles sliders op 0 behalve operating reserve 55% in positive mode: batterij charge 1500watt(production-consumption) production 676(wat er aan zon gemaakt word) consumption 104(wat er aan load gebruikt wordt)

Alles sliders op 0 behalve operating reserve 100% in positive mode: batterij charge 1500watt(production-consumption) production 676(wat er aan zon gemaakt word) consumption 104(wat er aan load gebruikt wordt)

Alles sliders op 0 behalve operating reserve 0% in Negative mode: batterij charge 567 watt(production-consumption) production 665(wat er aan zon gemaakt word) consumption 105(wat er aan load gebruikt wordt)

Alles sliders op 0 behalve operating reserve 25% in Negative mode: batterij charge 193 watt(production-consumption) production 675(wat er aan zon gemaakt word) consumption 107(wat er aan load gebruikt wordt)

Alles sliders op 0 behalve operating reserve 50% in Negative mode: batterij charge 0watt(production-consumption) production 670(wat er aan zon gemaakt word) consumption 108(wat er aan load gebruikt wordt) discharge 186 watt

Alles sliders op 0 behalve operating reserve 75% in Negative mode: batterij charge 0watt(production-consumption) production 676(wat er aan zon gemaakt word) consumption 108(wat er aan load gebruikt wordt) discharge 554 watt

Alles sliders op 0 behalve operating reserve 100% in Negative mode: batterij charge 0watt(production-consumption) production 679(wat er aan zon gemaakt word) consumption 111(wat er aan load gebruikt wordt) discharge 929 watt

Irradiance on 50%

Operating reserve

Alle andere sliders op 0
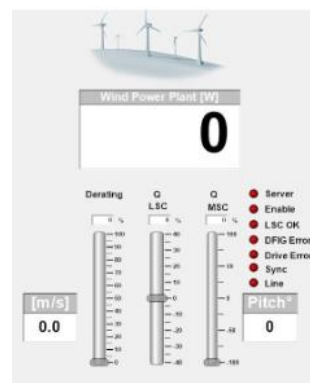
Image 4.1.30

Operating reserve% positive	Charge (watt)	Discharge (watt)	Production (watt)	Consumption (watt)
0	564	0	677	107
25	950	0	676	106
50	1390	0	677	106
75	1500	0	676	104
100	1500	0	676	104

Operating reserve% Negative	Charge (watt)	Discharge (watt)	Production (watt)	Consumption (watt)
0	567	0	655	105
25	193	0	675	107
50	0	186	670	108
75	0	554	676	108
100	0	929	679	111

Manual Control% charge	Charge (watt)	Discharge (watt)	Production (watt)	Consumption (watt)
0	5	0	672	105

	Charge (watt)	Discharge (watt)	Production (watt)	Consumption (watt)
25	375	0	673	107
50	750	0	667	107
75	1125	0	676	106
100	1500	0	671	104

Manual Control% discharging	Charge (watt)	Discharge (watt)	Production (watt)	Consumption (watt)
0	4	0	675	109
25	0	375	667	110
50	0	750	675	112
75	0	1125	673	111
100	0	1469	668	112

-

PV-Derating %	Charge (watt)	Discharge (watt)	Production (watt)	Consumption (watt)
0	4	0	671	107
25	4	0	673	108
50	4	0	671	107
75	4	0	673	106
100	4	0	670	108

Power factor	Charge	Discharge	Production	Consumption

	(watt)	(watt)	(watt)	(watt)
0.8	4	0	667	107
0.85	4	0	671	106
0.9	4	0	669	106
0.95	4	0	673	106
1	4	0	671	107

To start the motor

!!!Zorg dat de motor protection switch tussen de switchable cappicitor battery zit en tussen de star-delta switch!!!!!

!!!!De ….motor moet eerst op een paar instellingen gezet worden. Dit doen we in een stappenplan!!!!!

1. Set the resistive load to its left limit.

2. Switch off all consumers.

3. Turn on the power on the three-phase motor via the power switch and star/delta switch (UL-L = 400 V). The motor starts. The controller's digital display shows "----", indicating that the controller is performing automatic connection identification. If identification data from a previous measurement are still stored, the digital display indicates the instantaneous power factor (cos ф) of the downstream consumer. Simultaneously pressing all three buttons (+, - and Set) for at least 8 seconds causes the controller to repeat the connection identification procedure. This takes about 3 minutes. After that, the display indicates the actual value of cos ф.

4. Turn off the motor.

5. Set the values specified below on the reactive power controller.

Cos φ	ind 0.5	(mode number -1-)
Switching delay	5 s	(mode number -4-)
Deactivation time	5 s	(mode number -12-)

6. urn on the power for the three-phase motor via the power switch and star/delta switch (UL-L = 400 V)

7. Put the servo machine test bench into operation. The reactive power controller still has the connection and operating current identification data saved, so that the actual cos ф is displayed. The setpoint cos ф is 0.95.
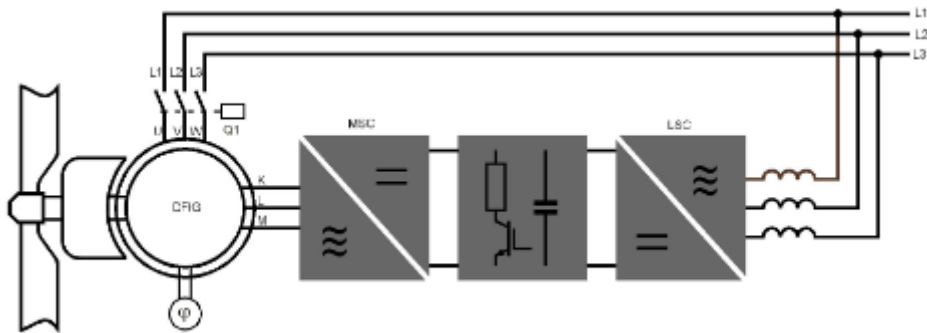
Experiments

Wind testen.

Image 4.1.31

Voor deze test hebben we de snelheid van de wind op een constante snelheid gezet van 11m/s

De Zonnenpannelen en de twee consumers zijn ook constant

Zon	Wind	Consumer1	Consumer11	Balancing point
0	-540	275	410	-170

Derating varieren. Lsc en msc op 0

Derating	Pitch	Power	m/s
0%	0	-540	11
25%	0	-540	11
50%	0	-540	11
75%	20	-180	11
100%	90	36	11

Lsc varieren en msc en derating op 0

LSC	Pitch	Power	m/s
40	0	-540	11
20	0	-540	11
0	0	-540	11
-20	0	-540	11

-40	0	-540	11

Msc varieren en lsc en derating op 0

msc	Pitch	Power	m/s
100	0	-360	11
50	0	-430	11
0	0	-540	11
-50	0	-550	11
-100	0	-460	11

----

m/s op 13

De Zonnenpannelen en de twee consumers zijn ook constant

Zon	Wind	Consumer1	Consumer11	Balancing point
0	-710	275	410	Ongeveer 0

Derating varieren. Lsc en msc op 0

Derating	Pitch	Power	m/s
0%	2	-710	13
25%	12	-550	13
50%	22	-355	13
75%	28	-185	13
100%	90	36	13

Lsc varieren en msc en derating op 0

LSC	Pitch	Power	m/s
40	2	-710	13
20	2	-710	13
0	2	-710	13

-20	2	-710	13
-40	2	-690	13

Msc varieren en lsc en derating op 0

msc	Pitch	Power	m/s
100	2	-600	13
50	2	-620	13
0	2	-710	13
-50	1	-740	13
-100	1	-668	13

The pitch is in degrees how the blades of the windmill turn. Pictured below.

Image 4.1.32

Though each wind power plant is designed and optimized according to the conditions prevailing at its installation site, the plant nonetheless fits into one of three main concepts as illustrated below.
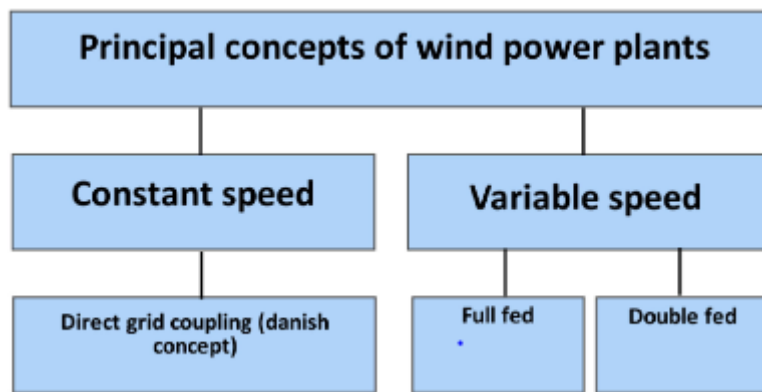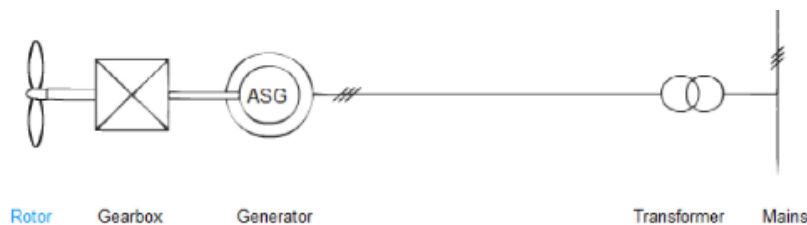
Image 4.1.33

Constant-speed

| Rotor | Gearbox | Generator | | Transformer | Mains |

Image 4.1.34

Variable-speed

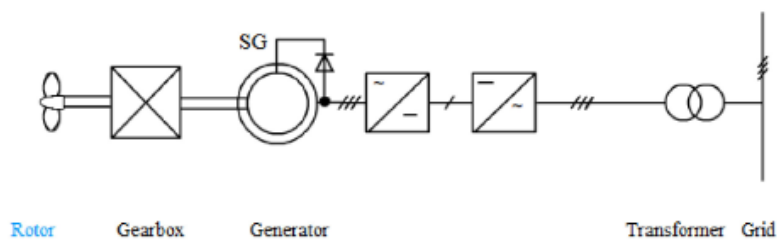| Rotor | Gearbox | Generator | | Transformer | Grid |

Image 4.1.35

the converters feed portions of the rotor currents to the grid, resulting in a flow of energy in this direction. About 10% of the plant's power is thus generated in the rotor and fed via the converters to the grid.Because the machine's excitation takes place via the converters, reactive power from the grid is not needed. Instead, the control system makes it possible to provide capacitive and inductive reactive power in accordance with the grid operator's specifications. The plant therefore contributes toward stabilizing the grid.
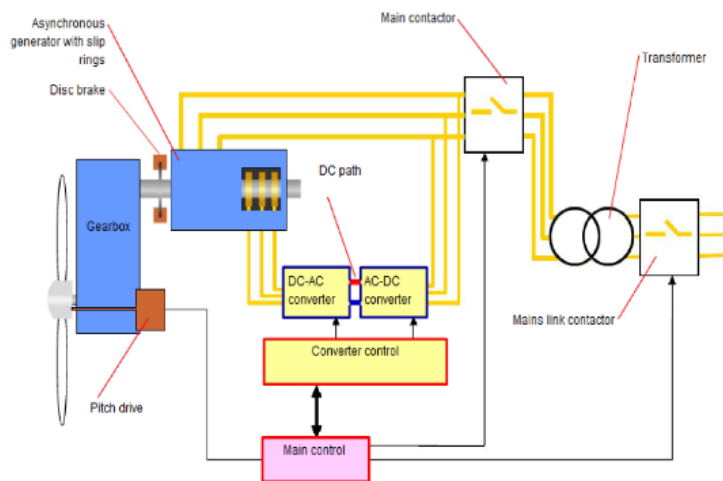
Speed control

Image 4.1.36

Function of a doubly-fed induction generator

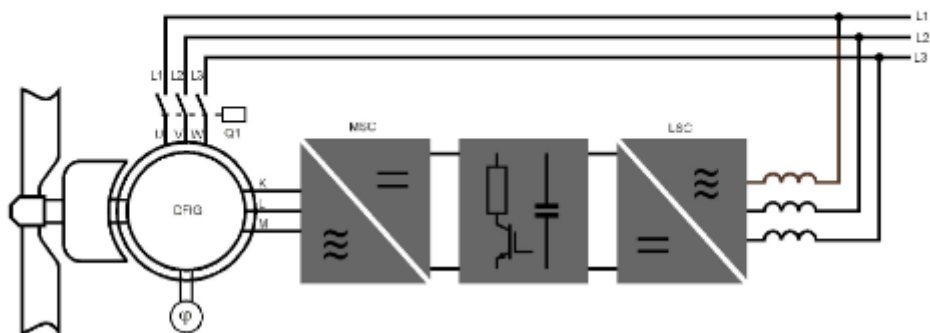Ilustrated below is the block diagram of a wind turbine with a doubly-fed induction generator.

Image 4.1.37

This one we used in our smart grid project.
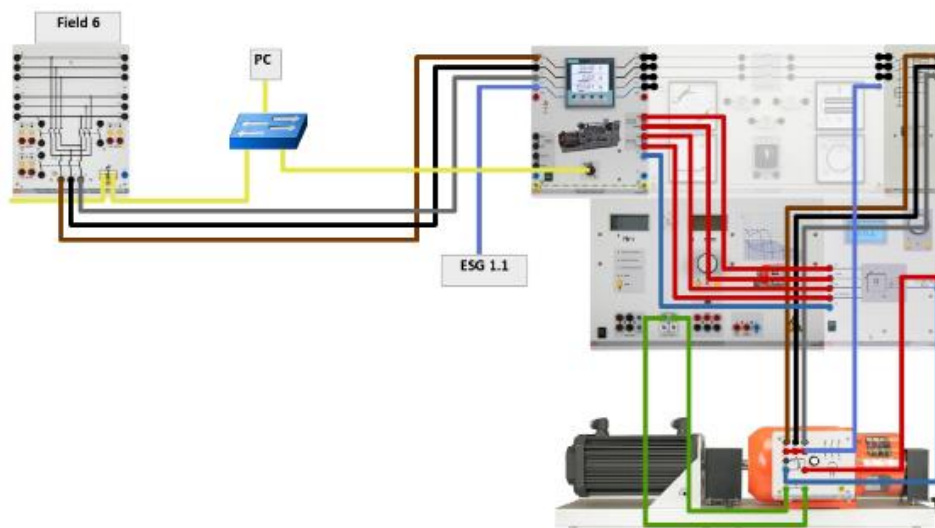
Cabling pumped storage.
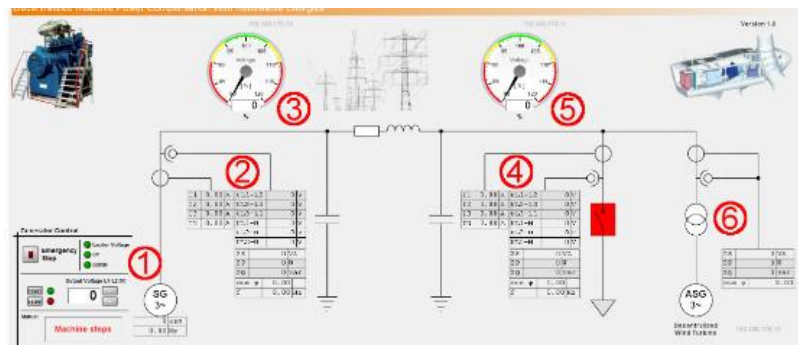

Image 4.1.39

Scada view

Figure 1: SCADA interface for "Smart grids: Reactive power compensation with a remotely located wind power plant"

Image 4.1.40

1. Generator control and status display: Starting and stopping the generator and setting of generator output voltage between the two phases L1 and L2.

2. Measurements at the start of the transmission or the generator: current, voltage, power, power factor and frequency.

3. Analog display of permissible difference from nominal operating voltage from the start of the line as a percentage (-10% in Europe according to European standard EN 50160). According to the standard, 100% refers to 230 V between L1 and N, or 400 V between L1 and L2. Depending on the local standard, the permissible amount may vary.

4. Equivalent display at the end of the line, at the consumer.

5. Equivalent analog display at the end of the line.

6. Display of power from the wind power plant.

synchronous machine SE2662-5Q.

- Nominal voltage: 400/230V, 50Hz

- Nominal currrent: 1.5A / 2.6A

- Nominal speed: 1500rpm

- Nominal power: 0.8kW

- Cos phi: 0.8 ... 1 ... -0.8

- Exciter voltage: 220V

- Exciter current: 1.6A

The speeds that needs to get 50 hz = ……rpm

4.2 Concept design (ESE)

4.2.1 SMART GRID

A smart grid is an energy network to which a smart measurement and control system has been added. This ensures that the supply of the various energy sources can be matched to the demand. If there is a surplus of energy, this surplus can be transferred to for example a battery. So in the ideal situation there will be no need to give energy back to the grid or provide the consumer from energy from the grid. You will create a balancing point at the grid as close to 0W as possible (so not giving or providing)

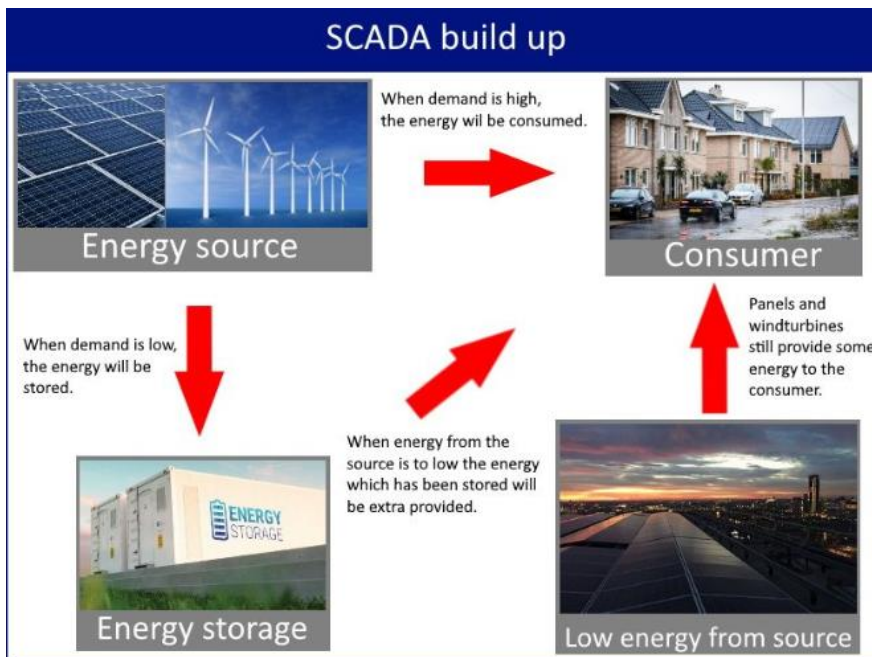In the image below is a small schematic on how the smart grid will operate.

Image 4.2.1: Smart Grid build up

As can be seen in the build up above, the most essential part is the battery. Because to make it "smart" the PLC needs to collect all the data for the consumer and the demand and make choices looking at the battery.

So if it needs to charge or discharge. To make it more understandable we created a SFC (sequential Function Chart) looking at all the available information and choices that need to be made.

A SFC is a graphical programming language used for programmable logic controllers (PLC). The SFC will have steps with associated actions, transitions with associated logic conditions and directed links between steps and transitions.

In the image below is the Sequential Function Chart (SFC). Is a first set-up of the code that needs to create the smart grid.
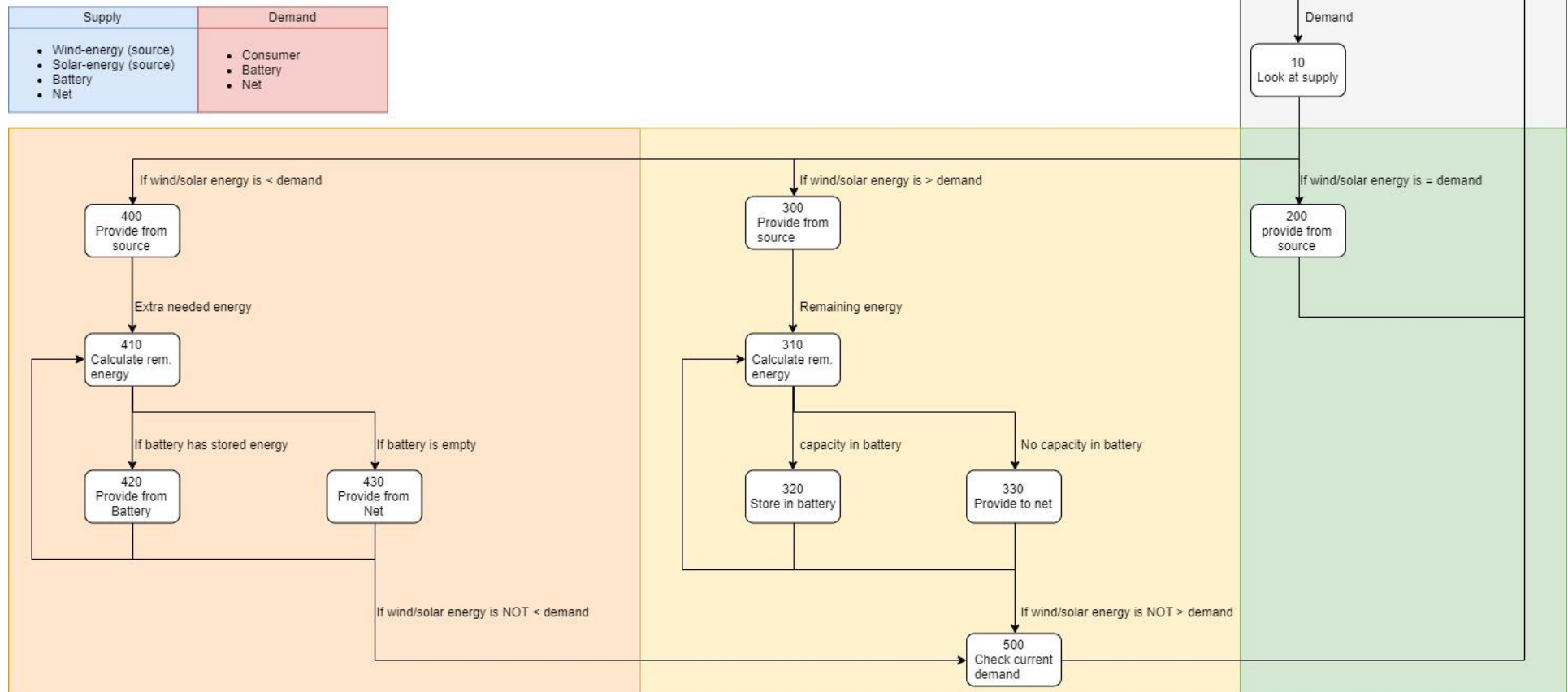
SFC

Image 4.2.2: Smart Grid SFC

What you see at the Smart Grid SFC is a "closed loop" SFC which contains conditions and actions.
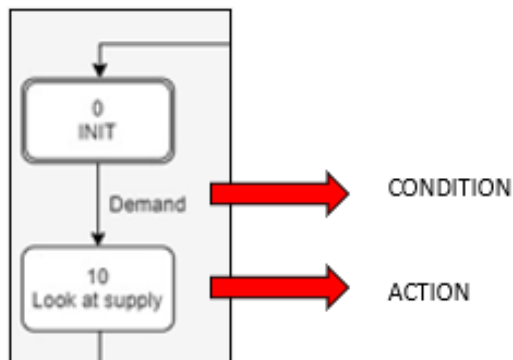

Image 4.2.3: Smart Grid SFC meaning

The SFC build up is as follows:

- **Step 0: Wait for demand**
  This is the initial step, here it waits until there is demand.

- **Step 10: Look at supply**
  Here will be looked at the battery level
    - If wind/solar energy is equal to demand the programm will go to **step 200**
    - If wind/solar is greater then demand the programm will go to **step 300**
    - If wind/solar is smaller then demand the programm will go to **step 400**

- **Step 200: Provide from source**
  Here the consumer will be provided directly from the source

- **Step 300: Provide from source**
  First the remaining energy will be calculated (supply – demand)
    - If there is capacity in the battery the programm will go to **step 320**
    - If there is no capacity in the battery the programm will got to **step 330**

- **Step 320: Store in battery**
  Here the remaining energy will be continuously calculated and stored if possible
    - If wind/solar energy is NOT greater then demand the programm will go to **step 500**

- **Step 330: Provide to net**
  Here the remaining energy will be continuously calculated and provided to the net if possible
    - If wind/solar energy is NOT greater then demand the programm will go to **step 500**

- **Step 400: Provide from source**
  First the extra needed energy will be calculated (demand - supply)
    - If there is capacity in the battery the programm will go to **step 420**
    - If the battery is empty the programm will go to **step 430**

- **Step 420: Provide from battery**
  Here the extra energy will be continuously calculated and provided if possible
  - If wind/solar energy is NOT smaller than demand the programm will go to **step 500**

- **Step 430: Provide from net**
  Here the extra needed energy will continuously calculated and provided from the net
  - If wind/solar energy is NOT smaller than demand the programm will go to **step 500**

- **Step 500: Check current demand**
  Here the current demand will be checked and goes back to the INIT to re do the cycle

As you can see the SFC is continuously looking at the values for the demand and supply and generates conditions to perform actions. There al also some loops in the SFC, this means it will perform it action and then will go back to see if the condition for this action is still true or if it has changes in the meantime. If it has changed it can perform a different action. To get out of the loop there is a different condition which will lead to a different step.

With this loop you will create an dynamic SFC always aware of changes in the Smart Grid.
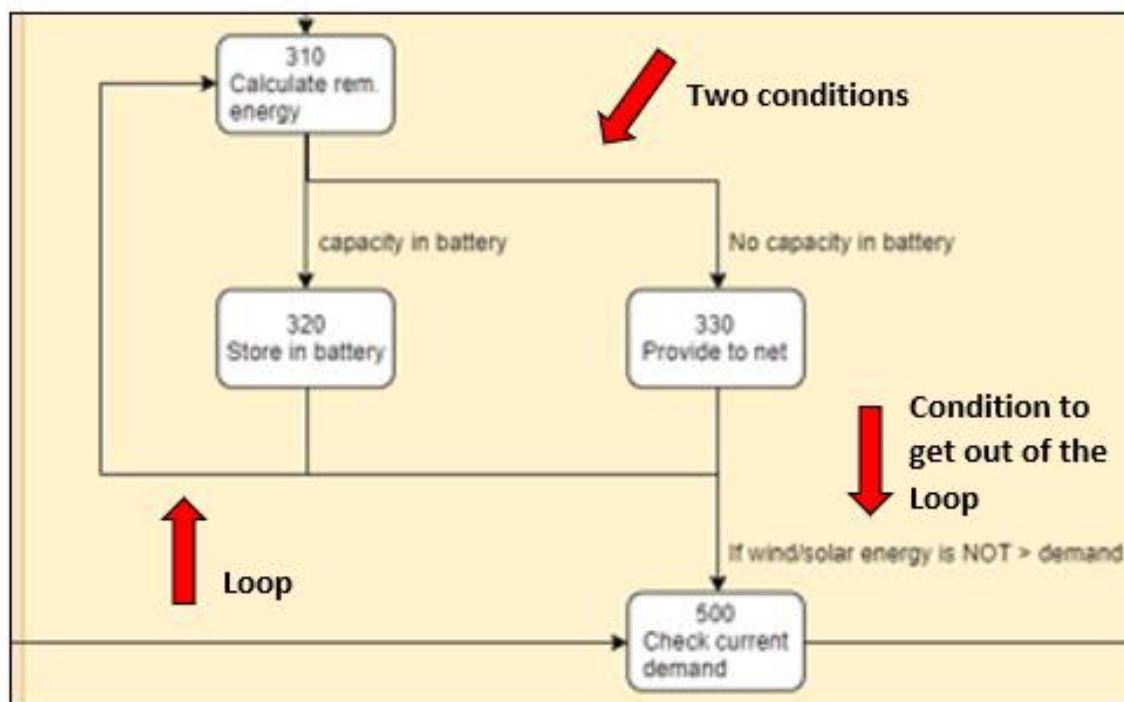

Image 4.2.4: Smart Grid SFC loop

4.2.2 Programming tests

To see what is possible within the Lucas Nülle program environment we are doing some small tests including some of the instruments and code.

Light

In this test we wanted to see if its possible to automatically switch a light bulb when the quality meter measures a certain voltage.

In the SCADA we added the quality meter and added an IO field to monitor the current and voltage on Phase 1.
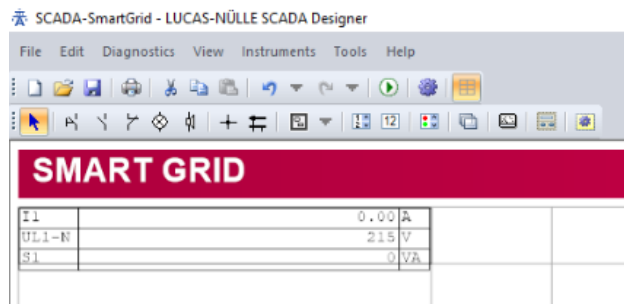

Image 4.2.5: Light SCADA

In the code we did the following. First we added the full variable list of the quality meter. It is possible to only add the ones that are needed but we decided to add the full list in case we wanted to add some different functions.
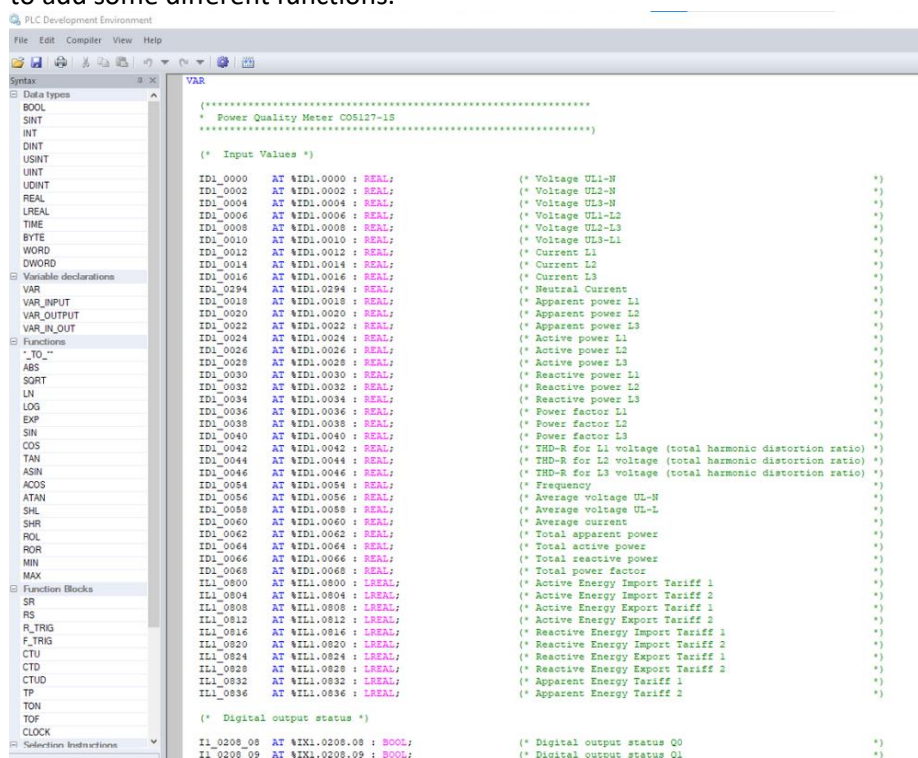

Image 4.2.5: List of variables

After adding the list of variables we added the code to make the light switch on and off. We created this in a function using an if/else statement.

The code is as follows to switch the light on when the voltage is 228 V of higher.

```
IF ID1_0000 => 228 THEN
Q1_60008_00 := TRUE;
ELSE
Q1_60008_00 := FALSE;
END_IF
```

The code is as follows to switch the light off when the voltage is lower then 228V.

```
IF ID1_000 < 228 THEN
Q1_60008_01 := TRUE;
ELSE
Q1_60008_01 := FALSE;
END_IF;
```
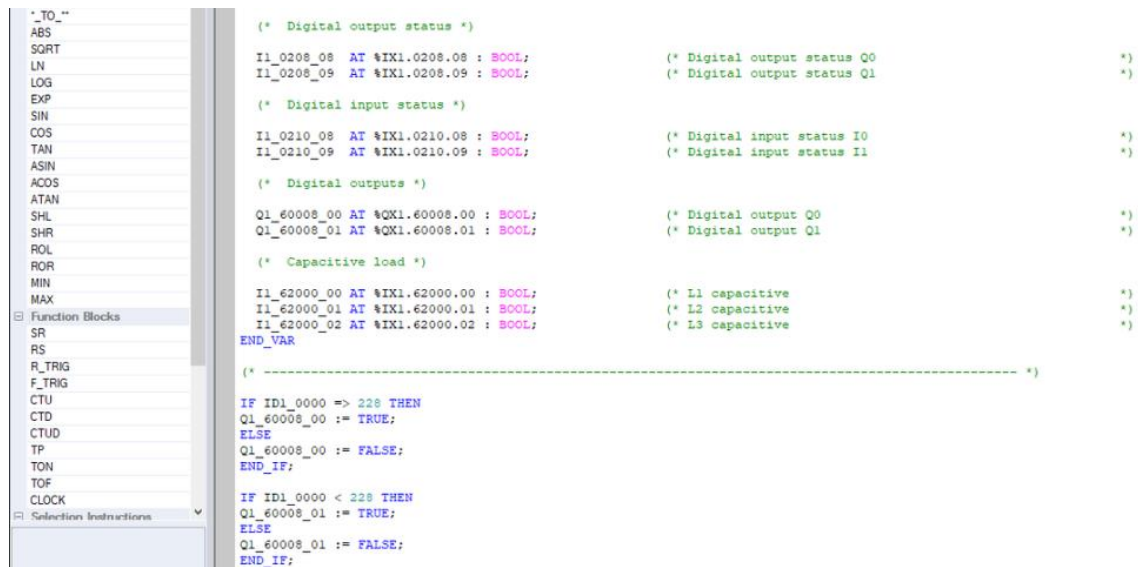

Image 4.2.6: Code

Conclusion

It is possible to add the variables from the instruments, read their values and re-use them to create functions to for example set an output high or low.

4.2.3 Battery

An important part of the SMARTGRID is the battery. We will need the battery to store the energy when the demand is lower than the supply. And to provide energy when the demand is higher than the supply. In this situation you will not need the energy from the net and keep the so called balancing point at 0, so not giving or receiving from the grid.

1. PV, this is where the solar energy is generated, this is in DC voltage. From here the energy is converted with a converter to an AC voltage.

2. The battery, here the battery will store or provide energy in this scenario it is possible to determine it manually by putting it in manual control. The maximum what the battery can store is 1500 W, with the slider you can determine how many percent from the 1500 W you want to charge or discharge.

3. The consumer, the consumer is the "demander" in this network. How much Watts the consumer needs will be provided. If there is not enough from the PV the battery will provide extra and if that is also not enough then the rest will be provided from the grid.

4. The net, in an ideal situation you will only need energy or store energy in extreme situations to the net. In this scenario you can decide if you want to give to the net (positive) or provide (negative) from the grid.
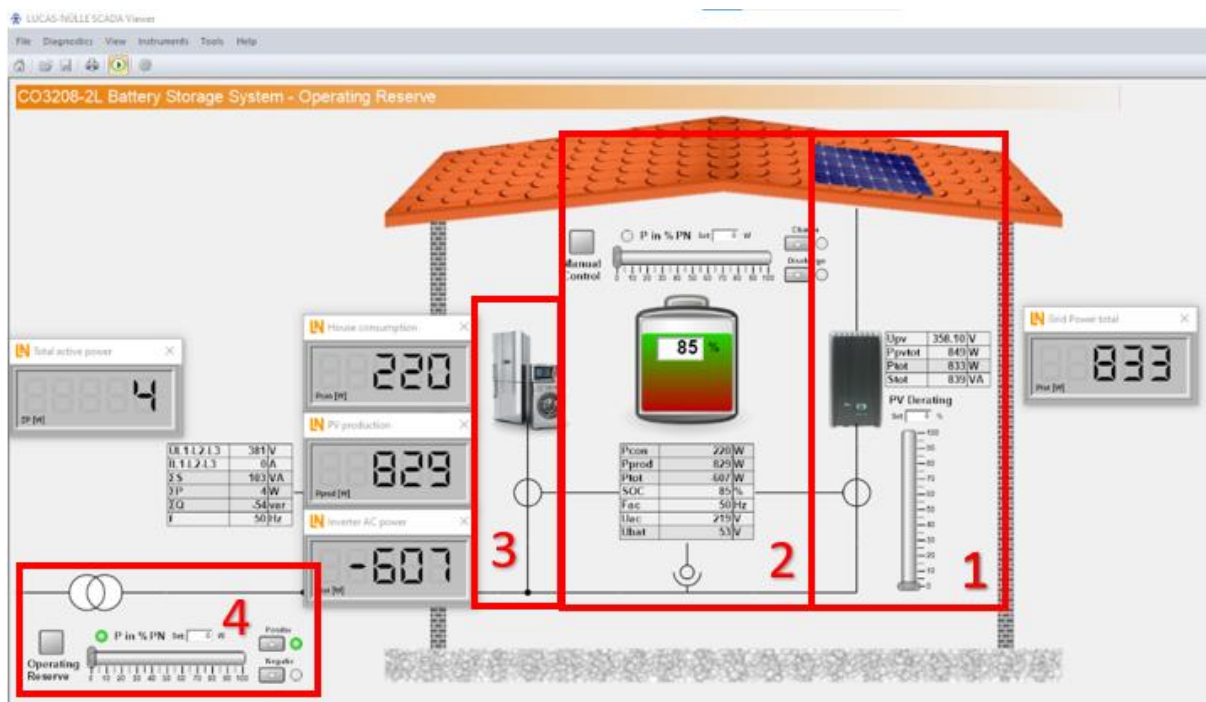

Image 4.2.7: SCADA

In the Lucas Nülle Labsoft environment there is a SCADA project called EPH4_RemoteControl. We going to have a closer look on how this is set up and what is important to know for creating a Smart Grid.

Keep in mind the values are constantly changing so the calculations and the screenshot may vary a little bit!

Charging the battery

In this situation we are producing 829 W from the PV and the consumer needs 220 W. We put the battery in auto mode. In this situation the battery needs to determine itself if it needs to charge or discharge and how much looking at the Operating Reserve. In the current situation we want the energy to the grid as close to 0 as possible, so we set the operating reserve at 0%.

220 W – 829 W = -609 W

-609 W from the battery means it is charging (the battery is seen as a source)
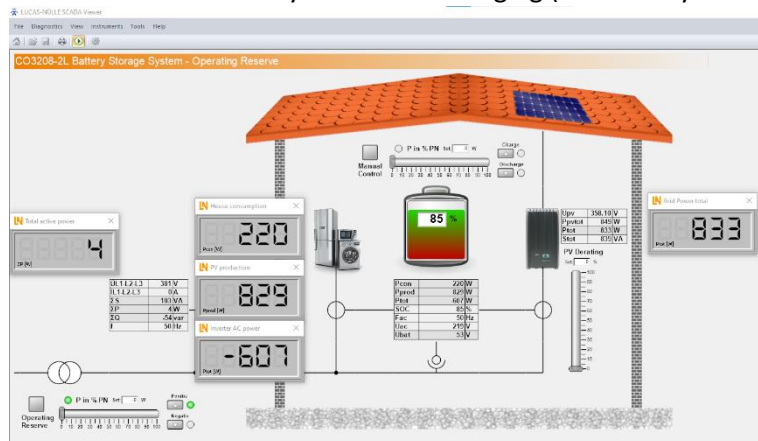

Image 4.2.8: SCADA

What happens when we put the Operating Reserve to a small percentage?

Here we put the Operating reserve on 10%, from 1500 W that is -150W "negative" so providing from the grid. We see that the PV is producing 833 W, the grid is providing 141 W and the consumer needs 220 W.

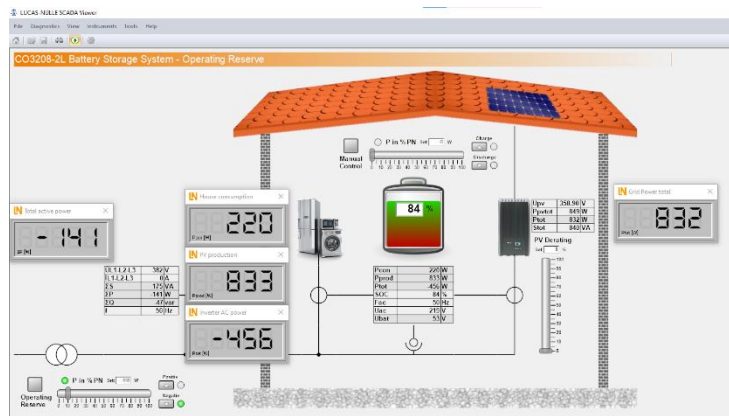220 W – 833 W + 141 W = - 472 W charging the battery

Image 4.2.9: SCADA/ Battery

Discharging the battery

To let the battery discharge automatically the demand needs to be higher than the supply. We are now producing 108 W from the PV and de consumer needs 217 W.
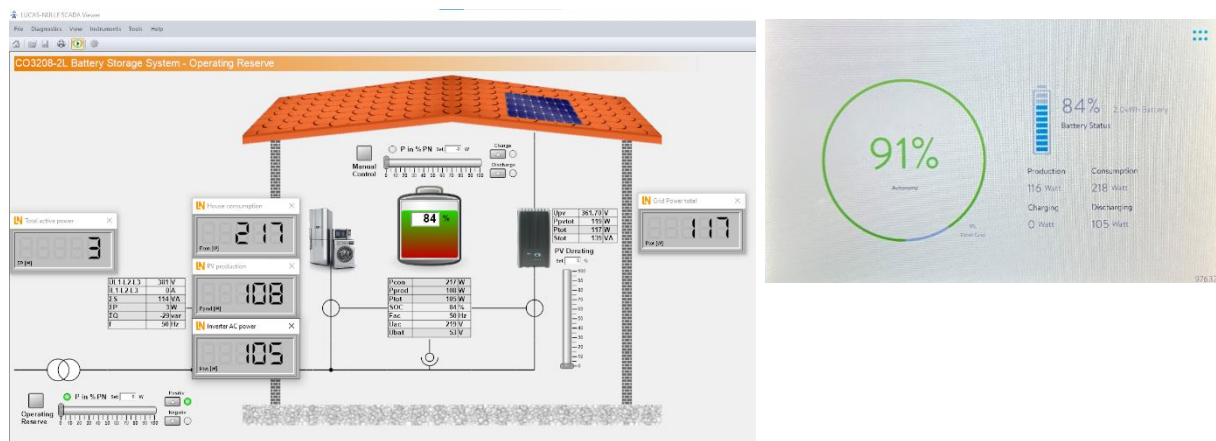
217 W – 108 W = 109 W discharging the battery

Image 4.2.10: SCADA/ Battery

Code

In the code behind that SCADA there are something interesting to know. First of al they created a auto and manual program. In our situation we want to make it auto, so the battery will decide whenever is needs to charge or discharge. Also we want to create a balancing point of 0W. So the operating reserve needs to be active and always at 0%.

The variables added are:

```
VAR
(* Rechargeable Battery System *)
(* Bool *)
RB_ManualControl        AT %MX1.0500.00 : BOOL;          (* Enable power control                        *)
(* Values *)
RB_Charge               AT %ML1.0040 : LREAL;            (* Charge value

RB_Consumption          AT %IL1.0000 : LREAL;            (* House consumption                           *)
RB_Production           AT %IL1.0001 : LREAL;            (* PV production                               *)

(* Programmable logic controller *)
(* Bool *)
PLC_ManualControl       AT %IX3.0000.00 : BOOL;          (* I0   Manual control (knop) (Battery)
PLC_SetStateCharge      AT %IX3.0000.01 : BOOL;          (* I1   Charge (knop) (battery)
PLC_SetStateDischarge   AT %IX3.0000.02 : BOOL;          (* I2   Discharge (knop) (battery)

PLC_ManualOR            AT %IX3.0000.03 : BOOL;          (* I0   Manual Operating Reserve (knop) (NET)
PLC_PositivOR           AT %IX3.0000.04 : BOOL;          (* I1   Positive Operating Reserve (knop) (NET)
PLC_NegativOR           AT %IX3.0000.05 : BOOL;          (* I2   Negative Operating Reserve (knop) (NET)

(* Values *)
PLC_SetCharge           AT %IL3.0000 : LREAL;            (* Value 1 Charge value battery vanaf SCADA ingesteld in %
PLC_SetOR               AT %IL3.0001 : LREAL;            (* Value 2 Operating Reserve value vanaf SCADA ingesteld in %
PLC_SetDerating         AT %IL3.0002 : LREAL;            (* Value 3 Derating PV value vanaf SCADA ingesteld in %

PLC_Charge : LREAL;

(* Steca Solar Converter *)
PV_Derating             AT %QL4.0040 : LREAL;            (* Power Derating %                             *)

(* Help variables *)
State_Dis_Charge : bool := false;
State_Negativ_Positiv : bool := false;

State        : (Auto, Manual, Battery);

ManualControl : R_Trig;
ManualOR : R_Trig;
(* Visuals *)
Visual_Manual           AT %QX3.0000.20 : BOOL;          (* Q20 Lampje op SCADA "Manual battery"
Visual_Charge           AT %QX3.0000.21 : BOOL;          (* Q21 Lampje op SCADA "Charge battery"
Visual_Discharge        AT %QX3.0000.22 : BOOL;          (* Q22 Lampje op SCADA "Discharge battery"
(* Operating reserve *)
Visual_ORManual         AT %QX3.0000.23 : BOOL;          (* Q23 Lampje op SCADA "Manual Operating reserve"
Visual_PositivOR        AT %QX3.0000.24 : BOOL;          (* Q24 Lampje op SCADA "Positive Operating reserve"
Visual_NegativOR        AT %QX3.0000.25 : BOOL;          (* Q25 Lampje op SCADA "Negative Operating reserve"

Visual_RBPower          AT %QL3.0009 : LREAL;            (* Value 10 (Set ... W Waarde op battery)
Visual_ORPower          AT %QL3.0010 : LREAL;            (* Value 11 (Set ... W Waarde op operating reserve)
Visual_Derating         AT %qL3.0011 : LREAL;            (* Value 12 (Set ... % Waarde op PV rating)
END_VAR
```

Image 4.2.11: VAR

We see the variables added from the battery and a lot of internal PLC variables coming from the SCADA, like the pushbuttons and status lights. What is most important for us are the battery values and the operating reserve status and values.

Next in the code they decide in which mode the program is running. In our case we need auto mode for the battery and manual mode for the Operating Reserve always at 0%. When this is true, the case function will go to auto and puts everything at false and the values at 0W.

```
ManualControl (CLK := PLC_ManualControl);    (* Zodra op de knop PLC_ManualControl wordt gedrukt wordt ManualControl TRUE*)
ManualOR (CLK := PLC_ManualOR);              (* Zodra op de knop PLC_ManualOR wordt gedrukt wordt ManualOR TRUE*)

(* hier wordt de CASE bepaald, AUTO, Manual of Battery *)
if (State = Manual) and ManualOR.Q then
  State := Auto;
elsif ManualOR.Q then
  State := Manual;
end_if;

if (State = Battery) and ManualControl.Q then
  State := Auto;
elsif ManualControl.Q then
  State := Battery;
end_if;

case State of
  Auto:  (* In AUTO (OR) zet hij de battery ingestelde waarde en de Operating Reserve op 0 *)
         RB_ManualControl := false;

         Visual_Manual := false;
         Visual_ORManual := false;

         Visual_PositivOR := false;
         Visual_NegativOR := false;

         Visual_Charge := false;
         Visual_Discharge := false;

         Visual_RBPower := 0.0;
         Visual_ORPower := 0.0;
```

Image 4.2.12: AUTO mode

What we noticed is that battery itself works in auto mode if we don't set the variable RB_ManualControl to TRUE.
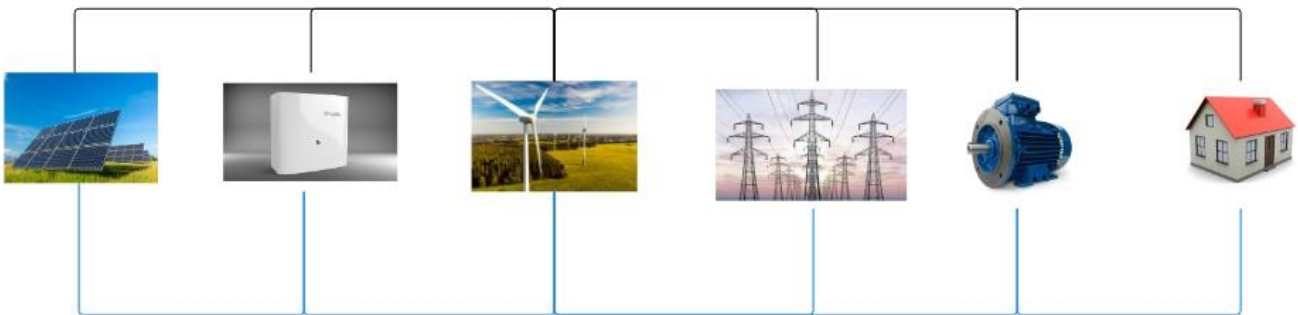
Conclusion

What we've seen is that the battery already has an automatic program (which we cannot access so far) that calculates if it needs to be charged or discharged looking at the production and consumption.

So it's possible to control the battery and creating a balancing point using the Operating Reserve value.

Chapter 5 Detailed design

5.1 Detailed design (IPS)

In the final detailed design, from an IPS perspective, the smart grid will be composed of the following: the solar panels, the wind turbine(s), a smart battery used for storage, an industrial-type load, a household-type load, and the busbars system used for interconnecting the loads and the voltage sources.

Image 5.1.1: Schematic for the SmartGrid System

For the detailed design, we did several tests and drew conclusions from this. We simulated a lot with our team from ips and ese in the lab of the lucas nuelle panels. We as ips have created a smart grid here. For ese, the task here was to keep the balancing point close to zero. As ipsers, therefore, the task of presenting all the values of our investigations to ese what they could expect.

We also looked at the Koningspleij in Arnhem, where there will be a solar park with four windmills. We have looked up all the technical specifications of this and we are trying to simulate this on a small scale in the lucas nuelle lab. Later in this design you will find out how we did this.

5.1.1 Electric scheme.

In the lucas nuelle lab we made a smart grid for this, a connection diagram was important so that we have the same thing every time.
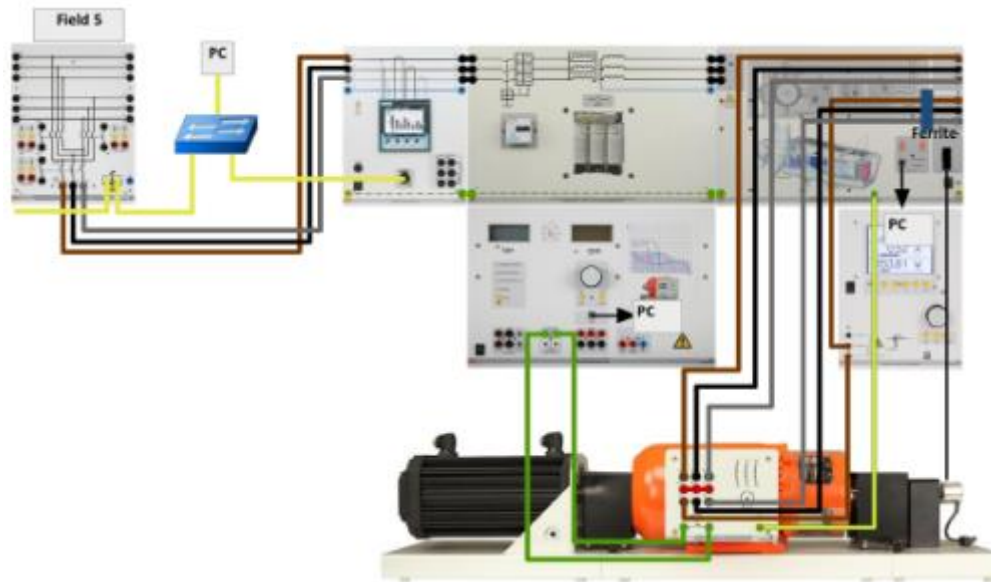
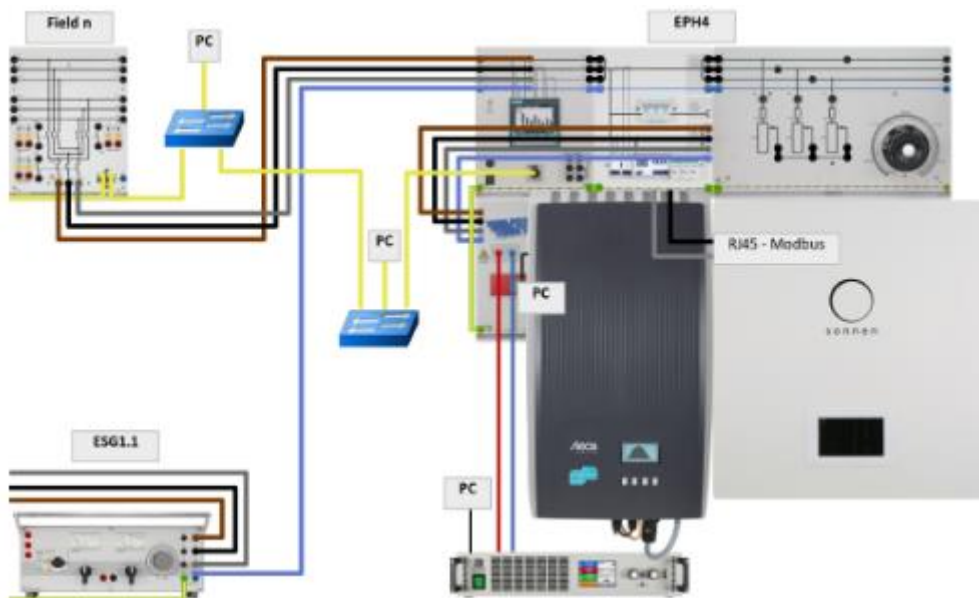**Windturbine scheme**

Image 5.1.2

Photovoltalic scheme

Image 5.1.3

Consumer 2
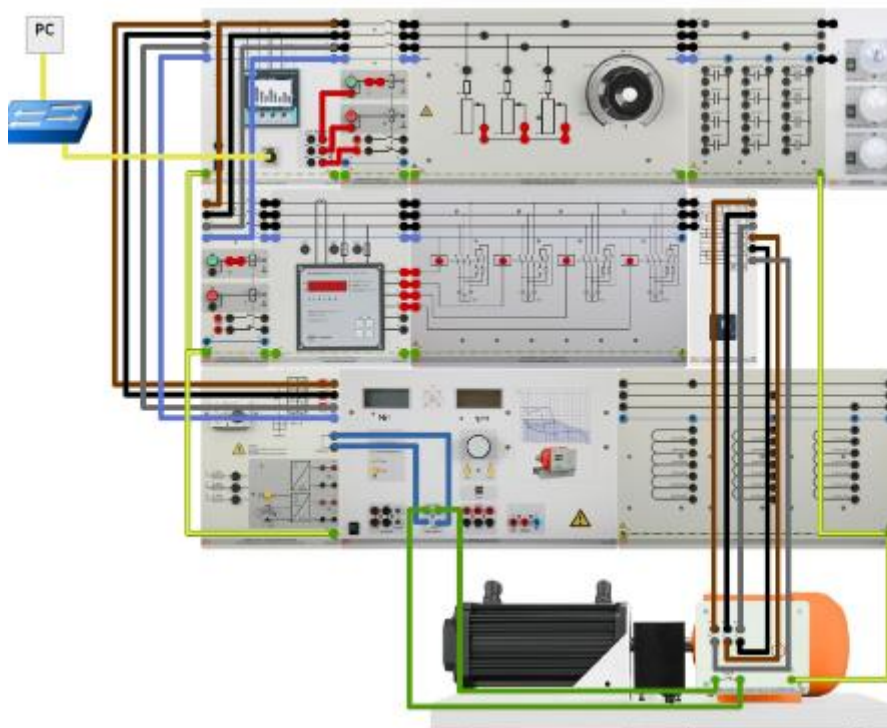
Image 5.1.4

Busbar system + consumer 1
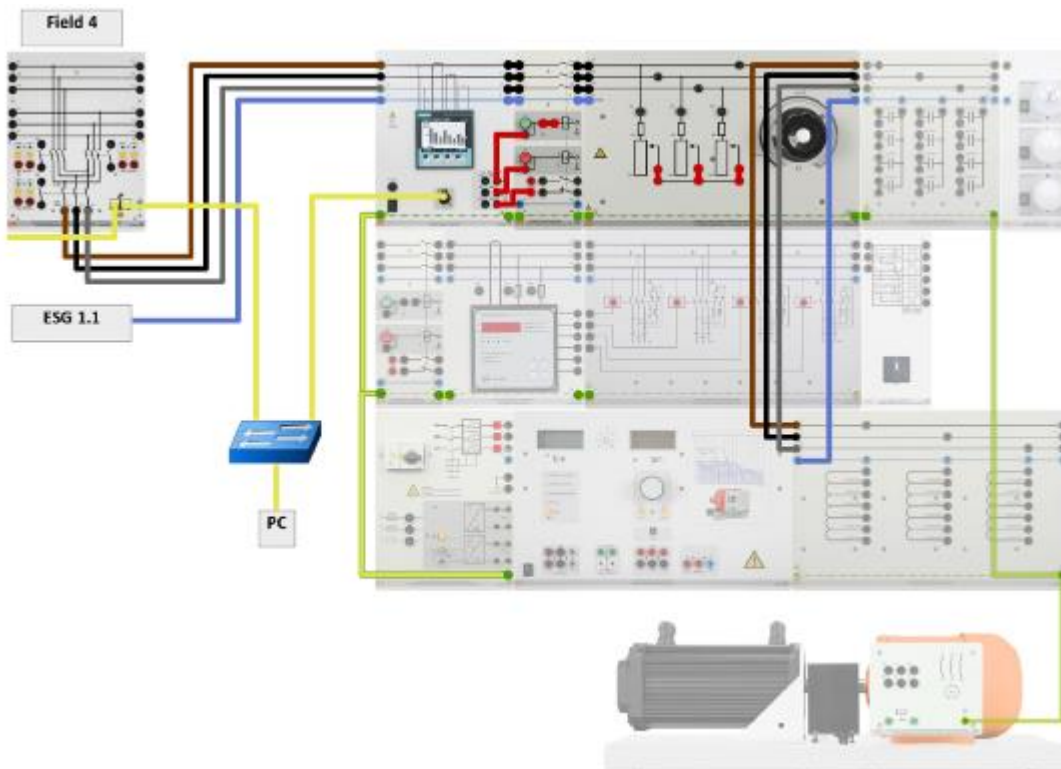
Image 5.1.5
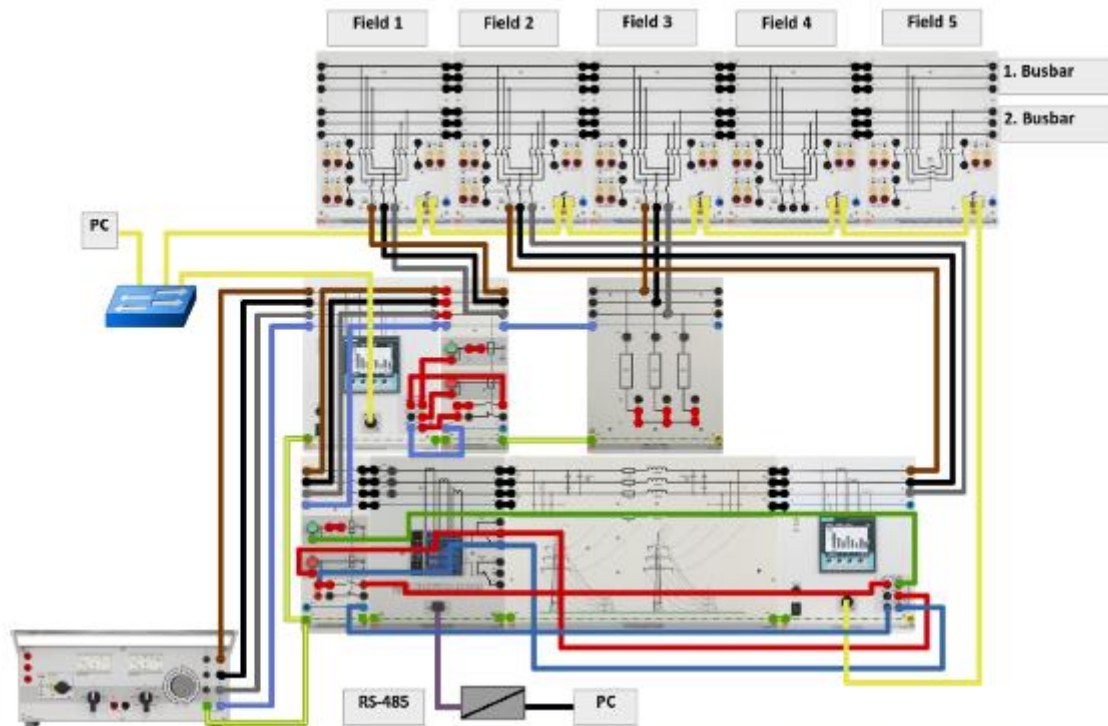
Image 5.1.6

the field layout
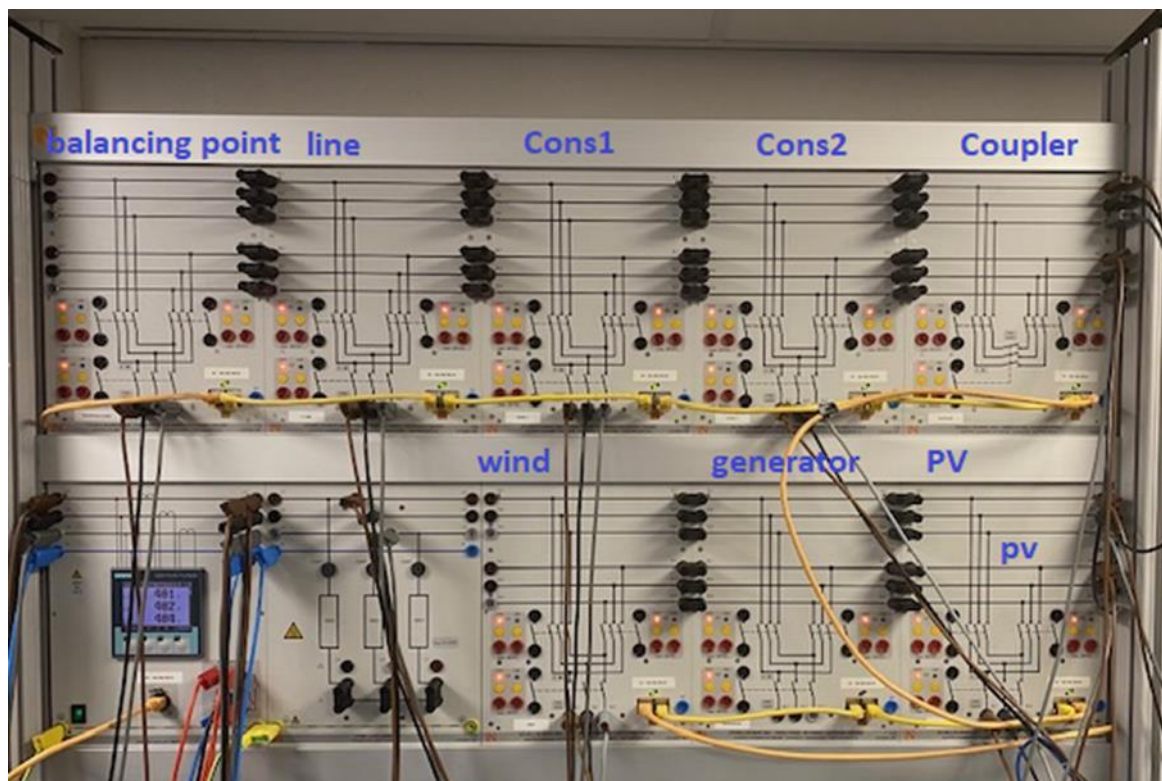
Image 5.1.7

5.1.2 Koningspleij Specifications.

Arnhem harbor case between the N325 and the IPKW and the new harbor where a new solar park with wind turbines is being installed.

Image 5.1.8

The location is circled in blue.

Image 5.1.9

Above is a picture of what it should look like.

This video is fun to watch and you will immediately receive a lot of information about the plan at the Koningspleij.

https://youtu.be/qM6OSVbAB8s

energy generators

Wind

The turbines that are being built at the Koningspleij wind farm are made by enercon. The type E-115 EP3, which will soon provide Arnhem with sustainable energy, is the first in its series in our country. The turbine has a capacity of 4.2 MW and is 177.5 meters high.

Looking north at the head of the Nieuwe Havenweg (right next to the Pleijroute)

comes mill 1. A little further to the north follows mill 2, on the IPKW follows mill 3 and

mill 4 is located between the Oude Veerweg and the Westervoortse dike.

Who takes the energy that the mills produce?

Agreements have been made with Greenchoice for wind turbines 1, 2 and 4. Greenchoice supplies the

electricity for half to the municipalities in the region. There is a special tender for this

Unsubscribed. The other half will be made available to local residents.

When the turbines start operating at the end of 2021, Windpark Koningspleij will provide enough clean energy to supply as many as 11,000 households in the region with electricity. The four wind turbines have a total maximum capacity of approximately 17 MW and are expected to jointly generate 34.5 million kilowatt hours (kWh) of energy per year. Another comparison: in 2018, 649 million kWh of electricity was consumed in the municipality of Arnhem. With 34.5 million kWh, the four wind turbines cover more than 5 percent of this total electricity consumption.
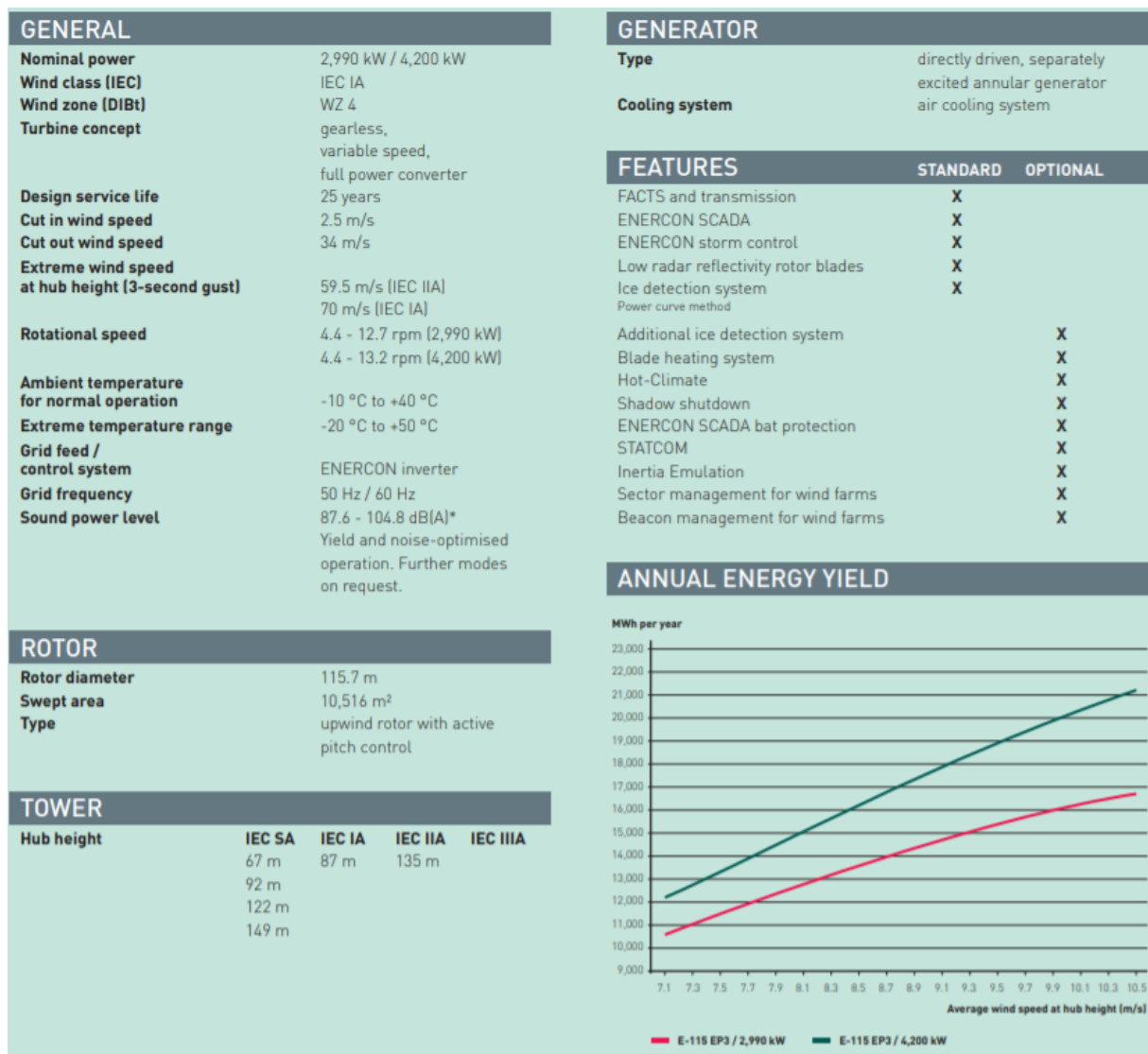
GENERAL

Nominal power	2,990 kW / 4,200 kW
Wind class (IEC)	IEC IA
Wind zone (DIBt)	WZ 4
Turbine concept	gearless, variable speed, full power converter
Design service life	25 years
Cut in wind speed	2.5 m/s
Cut out wind speed	34 m/s
Extreme wind speed at hub height (3-second gust)	59.5 m/s (IEC IIA) 70 m/s (IEC IA)
Rotational speed	4.4 - 12.7 rpm (2,990 kW) 4.4 - 13.2 rpm (4,200 kW)
Ambient temperature for normal operation	-10 °C to +40 °C
Extreme temperature range	-20 °C to +50 °C
Grid feed / control system	ENERCON inverter
Grid frequency	50 Hz / 60 Hz
Sound power level	87.6 - 104.8 dB(A)* Yield and noise-optimised operation. Further modes on request.

ROTOR

Rotor diameter	115.7 m
Swept area	10,516 m²
Type	upwind rotor with active pitch control

TOWER

Hub height	IEC SA	IEC IA	IEC IIA	IEC IIIA
	67 m	87 m	135 m	
	92 m			
	122 m			
	149 m			

GENERATOR

Type	directly driven, separately excited annular generator
Cooling system	air cooling system

FEATURES

	STANDARD	OPTIONAL
FACTS and transmission	X	
ENERCON SCADA	X	
ENERCON storm control	X	
Low radar reflectivity rotor blades	X	
Ice detection system Power curve method	X	
Additional ice detection system		X
Blade heating system		X
Hot-Climate		X
Shadow shutdown		X
ENERCON SCADA bat protection		X
STATCOM		X
Inertia Emulation		X
Sector management for wind farms		X
Beacon management for wind farms		X

ANNUAL ENERGY YIELD

MWh per year

Average wind speed at hub height (m/s)

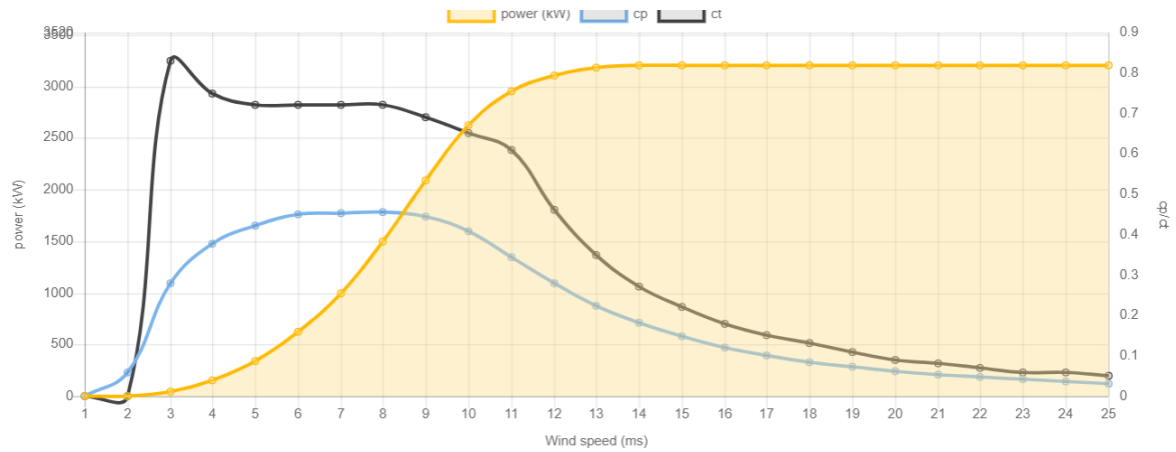E-115 EP3 / 2,990 kW   E-115 EP3 / 4,200 kW

Image 5.1.10

Image 5.1.11

This above is a profile of the prototype of the E-115 EP3 E3. The prototype has a nominal power of 3000kw.

Wind speed M/S	Power (Kw)	4 windmolens kw
1	0	0
2	3	12
3	48.50	194
4	155	620
5	339	1356
6	627.50	2510
7	1000	4000
8	1500	6000
9	2090	8360
10	2620	10480
11	2957	11828
12	3110	12440
13	3180	12720
14	3200	12800

At a wind speed higher than 14 m/s, the energy generation remains equal to 3200 kW. This is only changed again when the wind speed is lower or goes over the (cut-out) speed, then nothing is generated anymore.

Power

Rated power: 3,000.0 kW

Cut-in wind speed: 2.5 m/s

Rated wind speed: 12.8 m/s

Cut-out wind speed:34.0 m/s

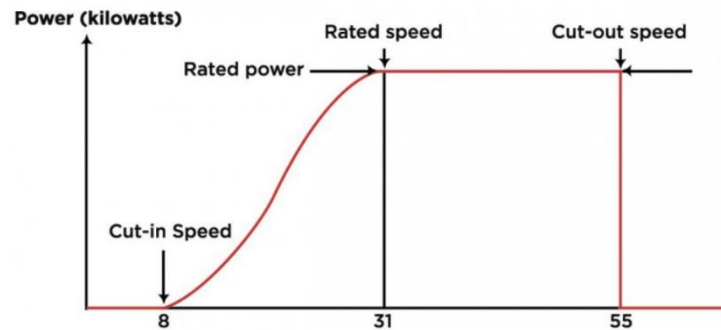Survival wind speed:70.0 m/s

Wind zone (DIBt):III

Wind class (IEC):Ia

Image 5.1.12

At a height of 50 meters. We measure the maximum speed on days 15-01-2021 and 15-04-2021 and 15-07-2021 and 15-10-2021. Hourly wind speed in m/s

We found these values on the website of NASA. The links for this can be found in the source list.

Time hour	15-1-2021 Wind speed m/s	15-4-2021 Wind speed m/s	15-7-2021 Wind speed m/s	15-10-2021 Wind speed m/s
0	12.73	5.4	7.16	8.95
1	12.5	4.92	6.63	9.63
2	12.18	4.42	6.28	9.04
3	11.95	3.95	6.44	9.17
4	11.91	3.6	5.19	9.8
5	11.73	3.16	4.47	9.7
6	11.55	2.83	4.9	9.56
7	11.48	3.41	5.65	8.3
8	10.99	3.5	6.48	8.07
9	9.88	3.55	6.06	8.25
10	9.67	3.64	6.1	7.59
11	9.57	3.76	6.61	7.09
12	9.69	3.89	7.3	6.59
13	9.34	4.02	8.26	6.17
14	9.17	4.21	9.13	5.8
15	9.19	4.48	9.76	5.37
16	9.08	4.76	9.95	5.45
17	8.91	5.24	9.86	5.98
18	8.52	6.68	9.73	6.25
19	7.86	8.0	9.39	6.11
20	7.01	8.54	8.08	5.76
21	6.14	8.42	7.38	5.38
22	5.83	7.62	7.53	4.95
23	6.28	7.41	7.27	4.45

These are profiles that we have made in the simulation program windsim. Here we have graphed the wind speed and time. With this we simulate a day from 2021. Now the plan was to also include the values that have to do with the Koningspleij. Unfortunately we have not yet found out how to do this so this is a nice challenge for the next group if it is at all possible to do.
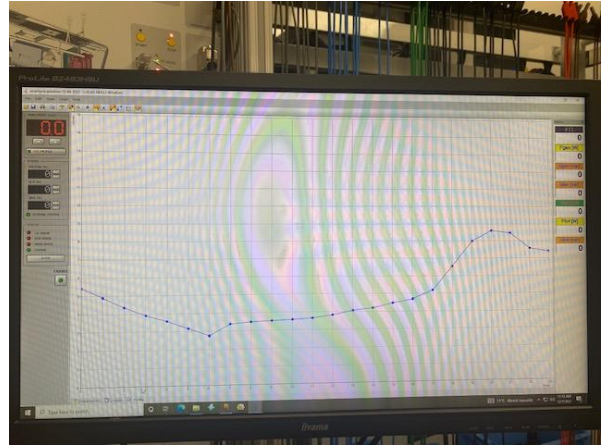
15-01-2021

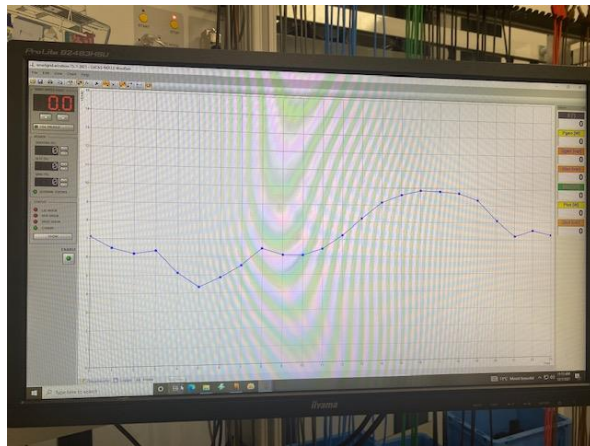*Image 5.1.13*

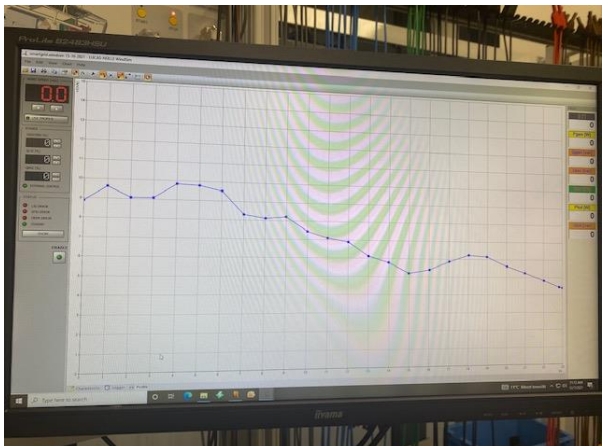15-04-2021

Image 5.1.14

15-07-2021

Image 5.1.15

15-10-2021

Image 5.1.16

We also looked at what the windmill prototype yields at which wind speed. We have also done this for the program windsim, which contains fixed values.

The power delivered when we use the values of windsim:

Windspeed (m/s)	Pgen(w)	Ptot(w)
1 m/s		
2 m/s	0	
3 m/s	0	-24
4 m/s	0	-90
5 m/s	50	-50
6 m/s	95	-10
7 m/s	150	60
8 m/s	230	160
9 m/s	315	270
10 m/s	420	420
11 m/s	540	560
12 m/s	620	660
13 m/s	720	760
14 m/s		
15 m/s		

3.8 m/s is the switching moment when the wind speed is above this, the windmill generates power. Below this, there is too little power from the wind and the windmill will not deliver anything.

In this table you can see the wind speed and what the generator of lucas nuelle generates. And besides, what a! Windmill on Koningspleij. And also how much is generated with four windmills.

So by running the time program on windsim that we made on windsim. You can easily see by means of this table what would be generated on the royal square.

wind speed (m/s)	Pgen watt (lucas nuelle	P (kw) koningspleij	With the four windturbines(kw)
0	0	0	0
1	0	0	0
2	0	3	12
3	0	48	192
4	0	155	620
5	50	339	1356
6	95	627	2508
7	150	1000	4000
8	230	1500	6000
9	315	2090	8360
10	420	2620	10480
11	540	2957	11828
12	620	3110	12440
13	720	3180	12720
14	720	12800	51200

Y-as is the power in watt x-as is the windspeed in m/s
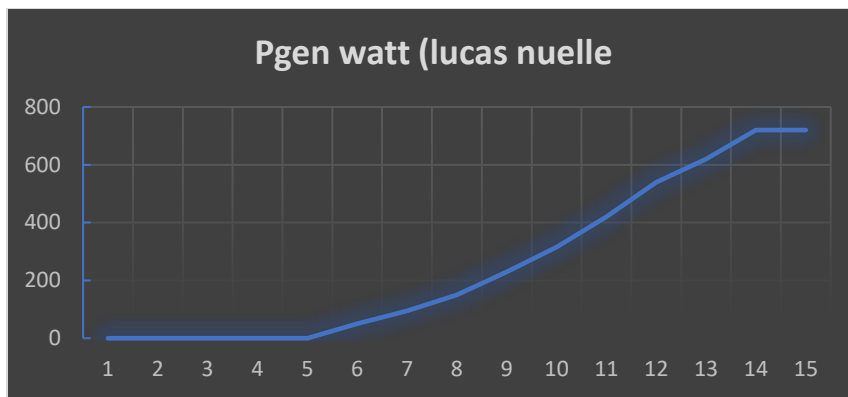
Image 5.1.17

Y-as is the power in Kilowatt x-as is the windspeed in m/s

Image 5.1.18

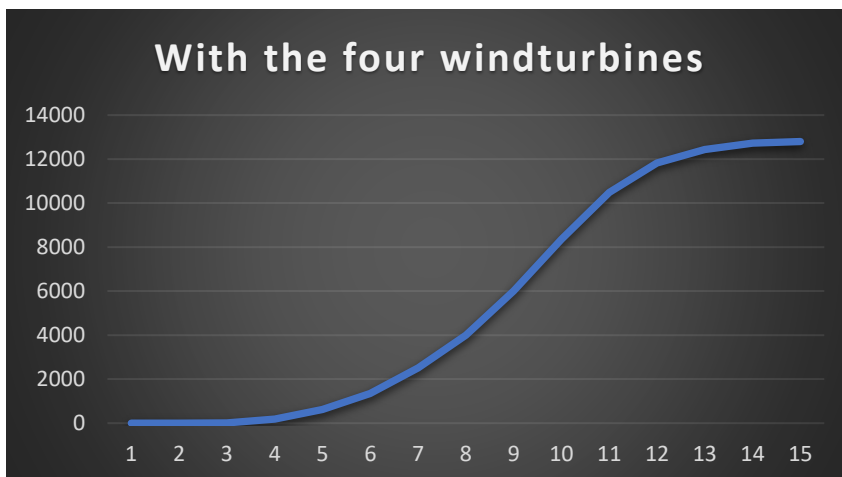Y-as is the power in Kilowatt x-as is the windspeed in m/s

Image 5.1.19

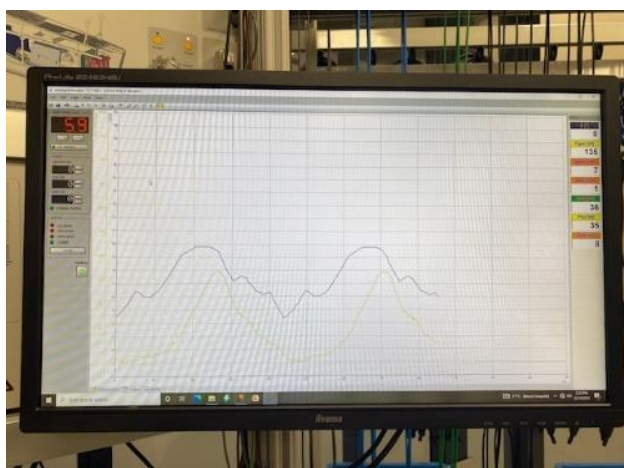Run Logger while simulating the created profiles.
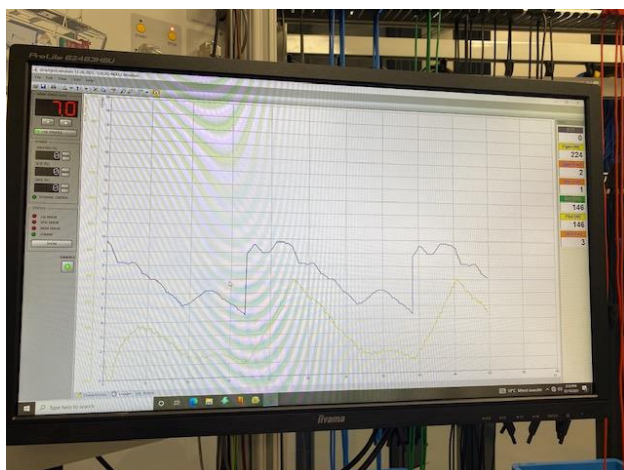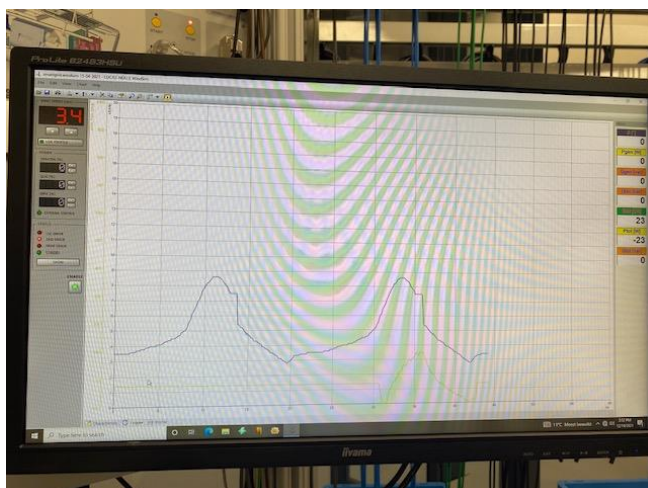

Image 5.1.20

Image 5.1.21

Image 5.1.22

Sun

Zonnepark Koningspleij Arnhem is an example of a wonderful sustainable project in which we combine energy production and a good integration into the landscape: the solar park is ideally situated between the Pleijroute (N325), the Nieuwe Haven and Kleefsewaard industrial park and therefore not visible from the homes in the area. Sunvest ensures double use of the location: sheep can graze under the solar panels. In addition, Zonnepark Koningspleij Arnhem will provide a home for wild bees and insects, for example by installing insect hotels. For this, Sunvest works together with local entrepreneurs from Arnhem. In addition, Sunvest is in talks with the Dutch Cultural Landscape Association to find even more suitable design measures to contribute to biodiversity in and around Zonnepark Koningspleij Arnhem.

The complete PV system will have a capacity of approximately 13,365 kWp. The system can thus generate 11,266,695 kWh annually. For example, more than 3750 households are switching to green electricity.

ZONNEPARK KONINGSPLEIJ
Koningspleij Noord / Nieuwe Havenweg. 6827BA Arnhem.

29.700 zonnepanelen
Longi LR4072HPH-40
Huawei omvormers

Verwachte productie jaar 1
11.266.695 kWh

Rente (IRR): 4,0%
Lineaire aflossing
Looptijd 15 jaar

Image 5.1.23

EV Charging			
Number of chargers		199	-
Charge per session		19,5	kWh
# of sessions per day		1,35	-
Energy per charger / day		26,3	kWh
Total		5239	kWh

|	(Jan. 2020 avg. workday)		(weekend)	(Nov 17, 2018)	(Mar 4, 2019)	(May 12, 2019)		(Oct 1, 2020)
Time		kWh/h	kWh/h	kWh/h	kWh/h	kWh/h		kWh/h
00:00	1,95%	102	81	195	524	48		0
01:00	0,98%	51	41	194	513	48		0
02:00	0,59%	31	24	195	524	47		0
03:00	0,39%	20	16	194	524	47		0
04:00	0,49%	26	20	201	527	47		0
05:00	0,88%	46	37	207	534	47		0
06:00	2,05%	107	85	226	543	47		0
07:00	3,52%	184	146	226	559	51		0
08:00	4,49%	235	187	227	590	56		112
09:00	4,49%	235	187	218	546	51		454
10:00	4,20%	220	175	218	556	53		942
11:00	4,10%	215	171	269	555	54		1.159
12:00	4,10%	215	171	259	564	63		1.885
13:00	4,20%	220	175	247	557	60		1.463
14:00	4,30%	225	179	242	562	57		1.206
15:00	4,59%	240	191	248	544	52		1.701
16:00	7,23%	379	300	249	538	53		1.400
17:00	9,38%	491	390	249	537	53		822
18:00	9,47%	496	394	263	632	55		137
19:00	8,11%	425	337	261	601	53		8
20:00	7,03%	368	292	258	591	51		0
21:00	5,76%	302	240	256	568	46		0
22:00	4,59%	240	191	258	577	47		0
23:00	3,13%	164	130	259	586	47		0
		kWh/day		kWh/day	kWh/day	kWh/day		kWh/day
Per day	100%	5239		5619	13352	1233		11289
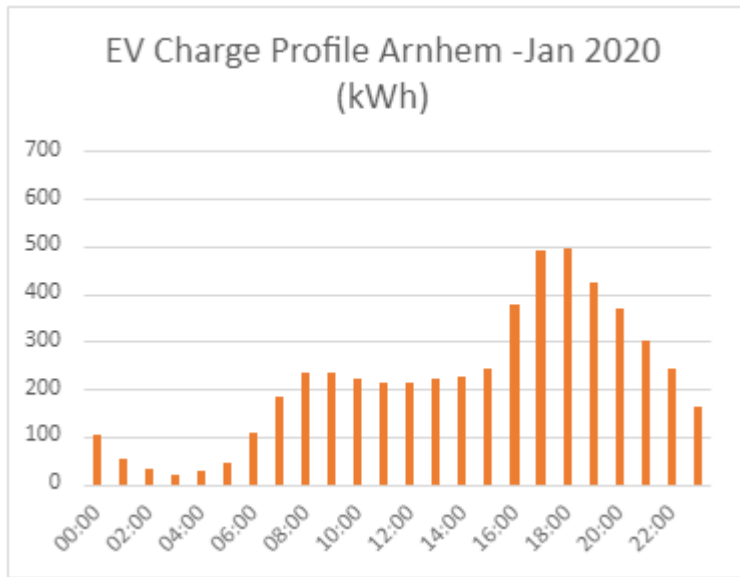
Image 5.1.24
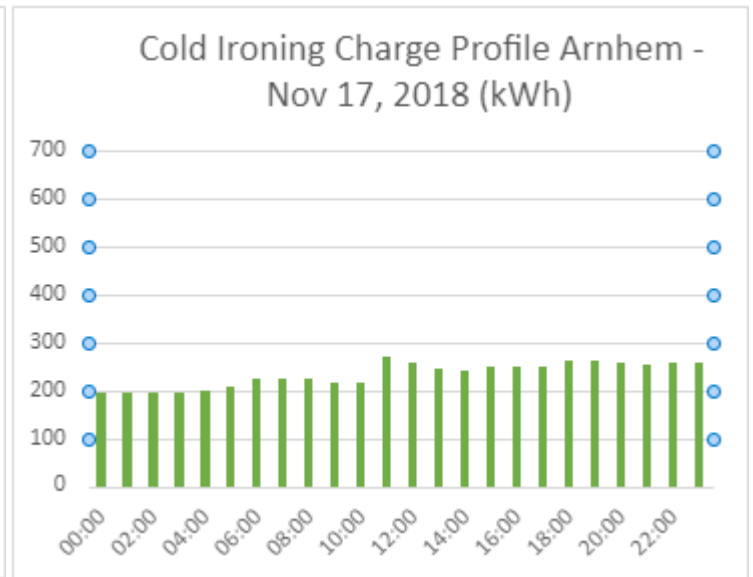
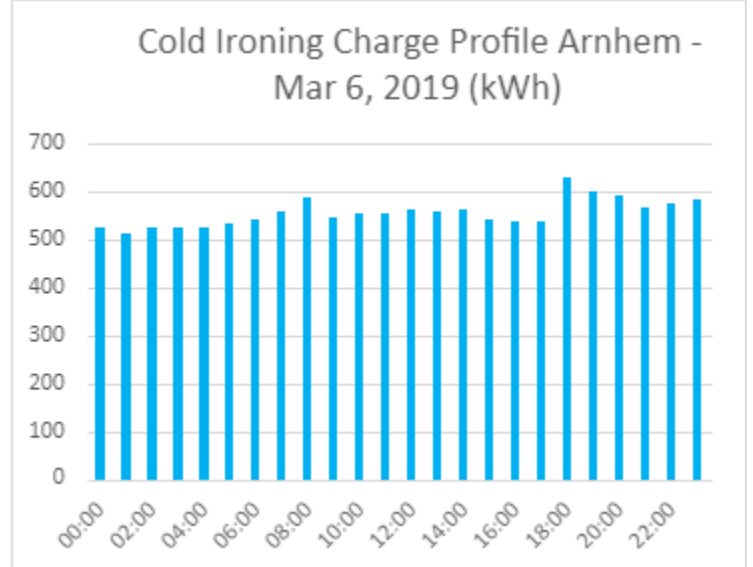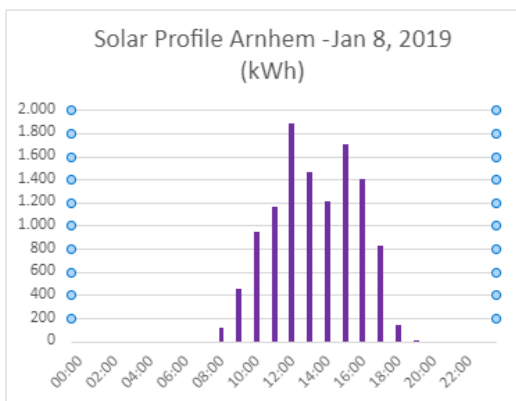*Image 5.1.25*
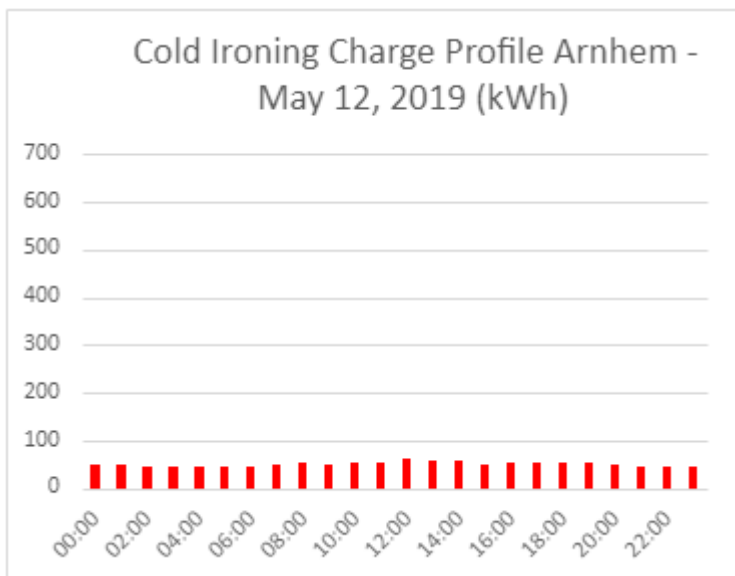
Image 5.1.26

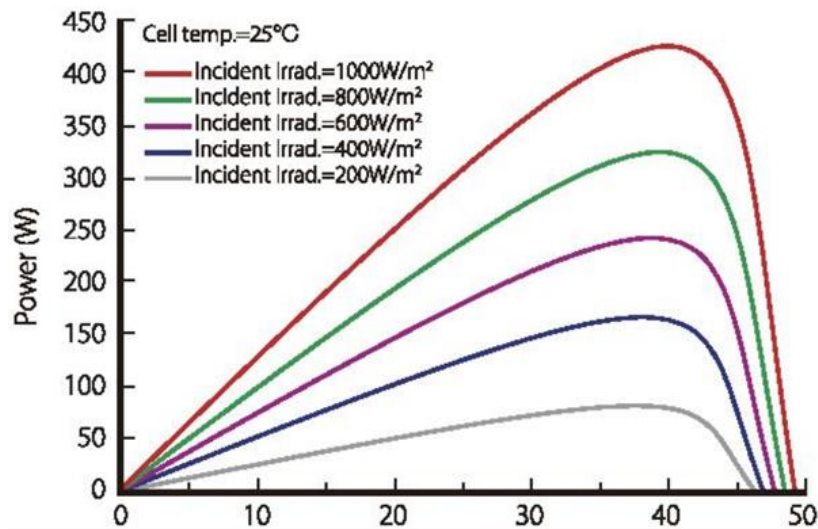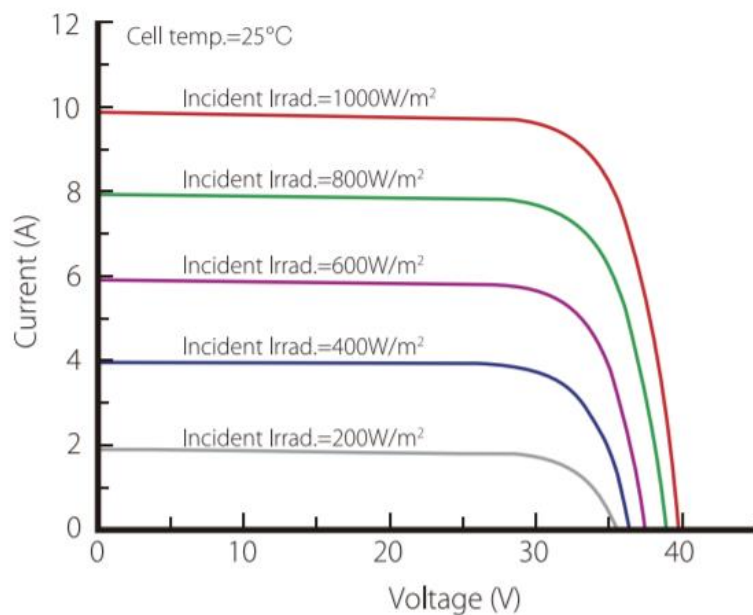*Image 5.1.27*

Image 5.1.28

Image 5.1.29

Image 5.1.30

There will be 29.700 solar panels at the solar park. The graphs above are from the the solar panel they are using. In the user manual of the Longi LR4072HPH-40 (the solar panels that is used there) There you can see the power/V and current/V on different irradiances. By calculating the current by using the irradiances that are above and below the settled irradiance, can make a pretty precise estimation of what the power could be. For how much irradiance there was on the dates, we used the NASA website where they give information about irradiance and a whole lot of more information. For the simulation there was a use of, we took the dates of 15th of January for the winter cycle, 15th of April for the spring cycle, 15th of july for the summer cycle and 15th of October for the autumn cycle. Here below we made some of the calculations for it for the time at exactly 12 pm.

Table of the total power on exactly 12 pm.

dates	Irradiance at 12pm in W/m^2	Power made by 1 panel in Watts	Power made in Watts with all the panels
15-01-2021	266	110	3.27 MW
15-04-2021	761.25	330	9.80 MW
15-07-2021	853	370	11.0 MW
15-10-2021	428.83	190	5.35 MW

The irradiance profiles that were effentuelly created are: the first one is spring, followed by summer, followed by autumn followed by winter.
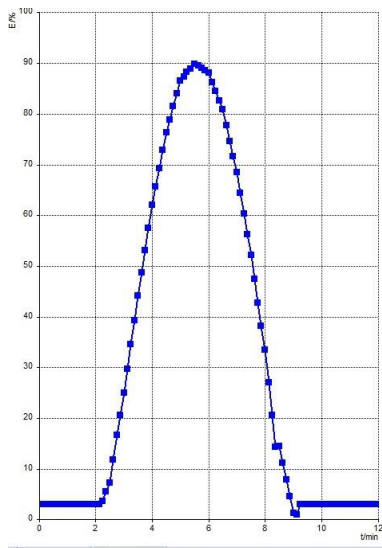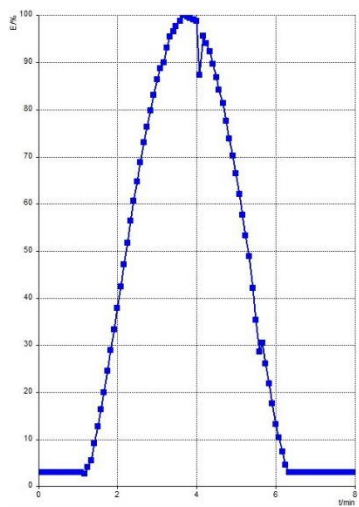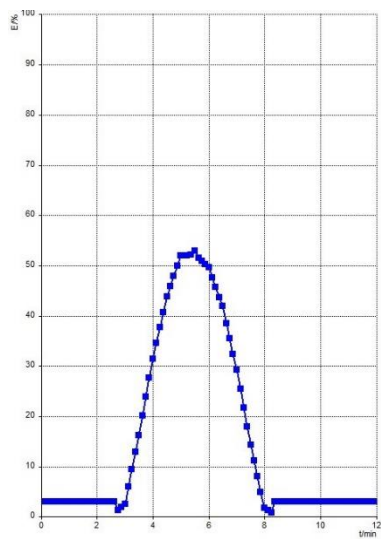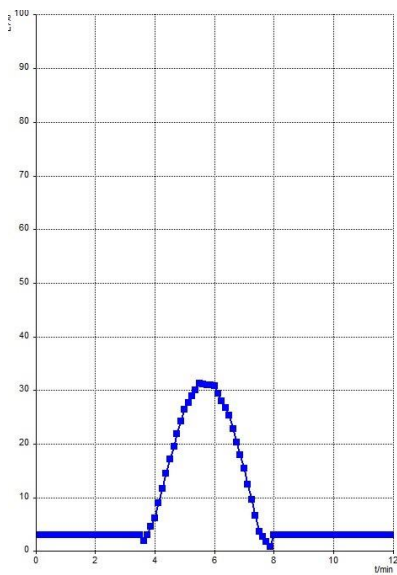

Image 5.1.31

Image 5.1.32

Image 5.1.33

Image 5.1.34

Note: The inverter will go to something called sleep mode when the PV-emulator will be below 40 W. this is because there is a loss of about 30W that is a fixed loss it seems like and the inverter will go to that sleep mode when the output of the inverter is below 8 W and it will turn on again after 10 W, but that will take a minute or 2 to turn on again. This problem is not a problem in real life use where the minutes off is nothing compared to a 24 hour day. But for a simulation of 8 minutes it is pretty problematic. How to fix the problem is to set the minimum value

Irradiance of the inverter	Power provided in (W)
10%	142
20%	286
30%	430
40%	575
50%	718
60%	864
70%	1006
80%	1150
90%	1294
100%	1435

Irradiance of one panel in KP	Power of one panel in (W)
1000	450
900	387.5
800	325
700	287.5
600	250
500	212.5
400	175
300	117.5
200	60
100	0

Loads

The energy that is generated is used to provide households in Arnhem with energy. Providing energy to ipkw. And charging a battery that can be used at the port. We also want to simulate this in Lucas Nulle's lab. For this we make two different loads: a variable load and a fixed load.De variabele load is meer naar het realistische toe.

Because in real life a lamp is not turned on at exactly 14:00 in a household, this all happens unexpectedly. So ips's job is to create a variable load. To properly test ese's program.

fixed load

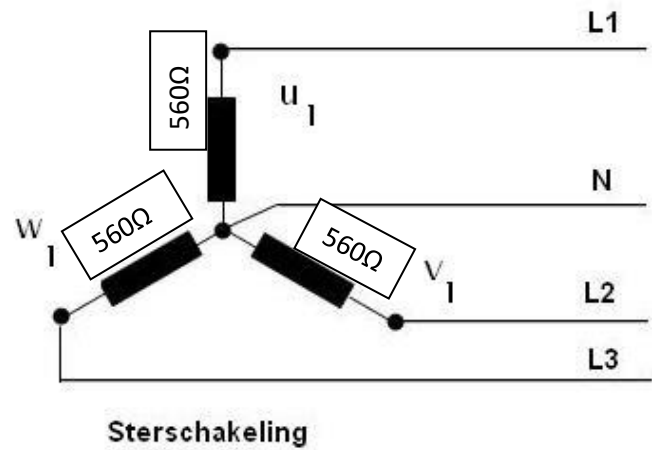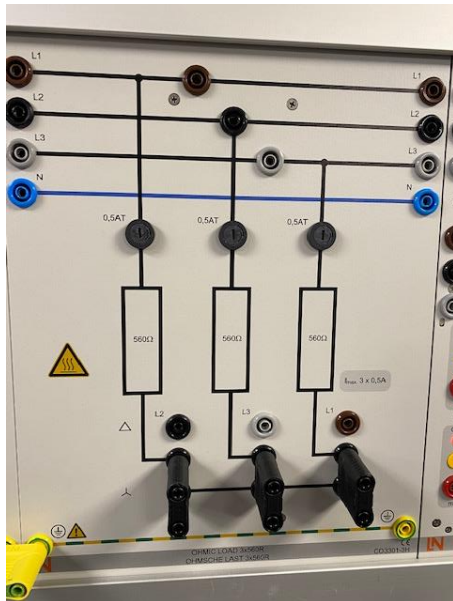This is the fixed load that we use in our smart grid.

Image 5.1.37

Image 5.1.36

The fixed load requires a constant value of around 270 watts, which we measured with a test to put the load on our consumer 1 and read it on the scada.
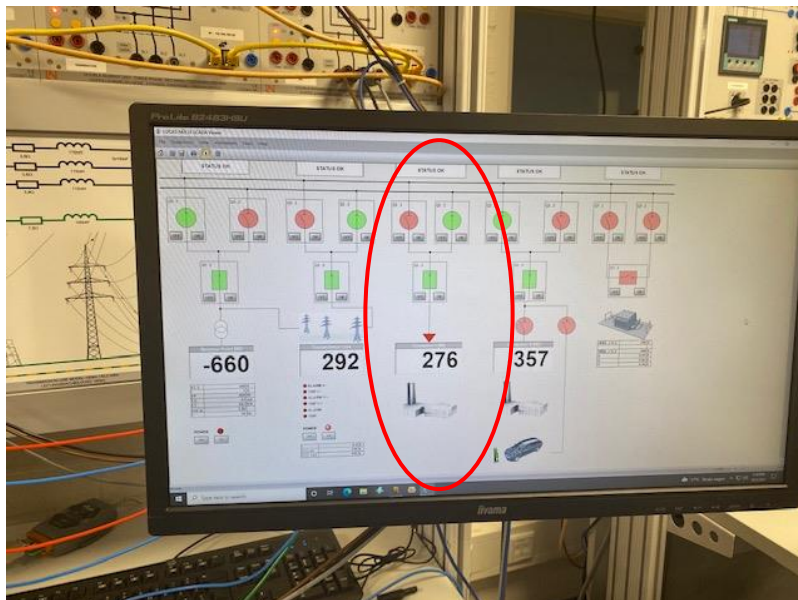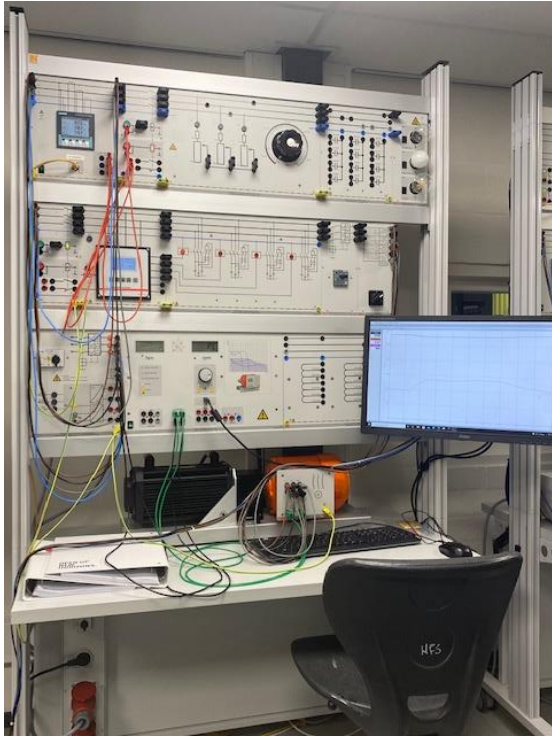

Image 5.1.38

variable load

We have created a variable load to load the grid with no constant values.

Now we have also made different profiles for this that load the net. Which look like this.

this is the setup where we make a variable load by means of a motor

Image 5.1.39

on the internet we have found a profile that imitates an industrial area with the energy consumption, this because we want to look at the energy consumption of the Kleve inn.
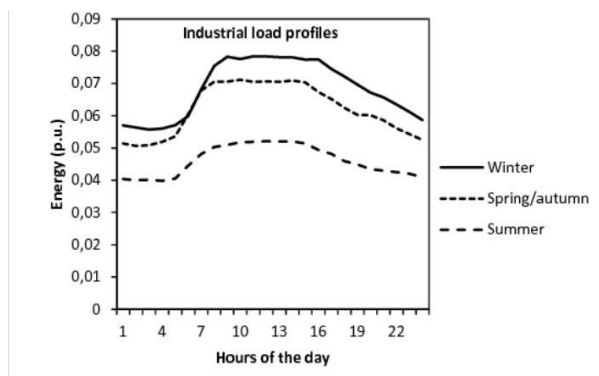
Image 5.1.40

here you can see how we created the profile.
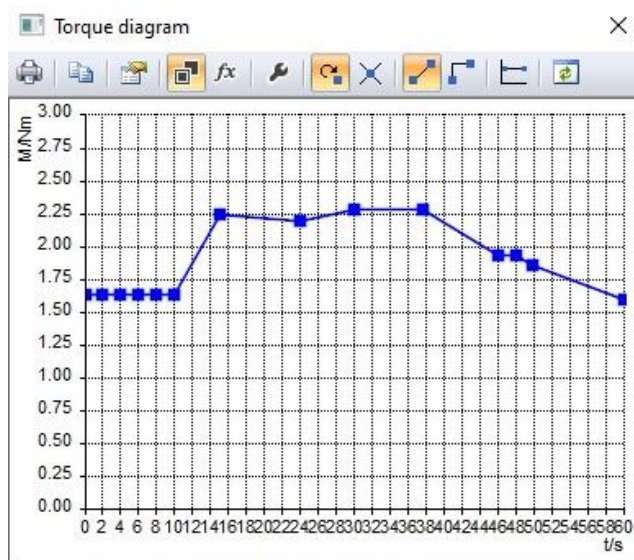
Image 5.1.41

Recorded profiles by running it. the first with a short time. and the second with a longer time.
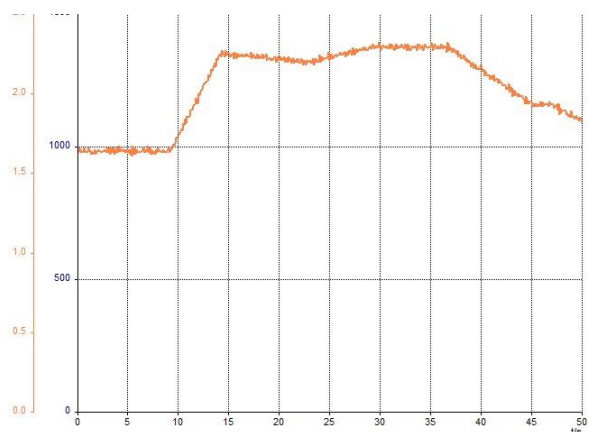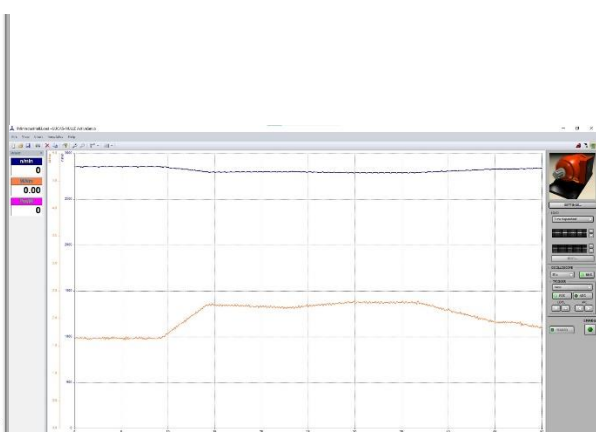
Image 5.1.42A   *Image 5.1.42B*

RPM	Active Power	cos phi	Nm
2960	195	0,91	0,27
2930	325	0,95	0,73
2900	444	0,96	1,2
2850	626	0,96	1,8
2800	790	0,95	2,3
	Values according to the online profile	0,59	0,7
		1,938571429	1,642857143
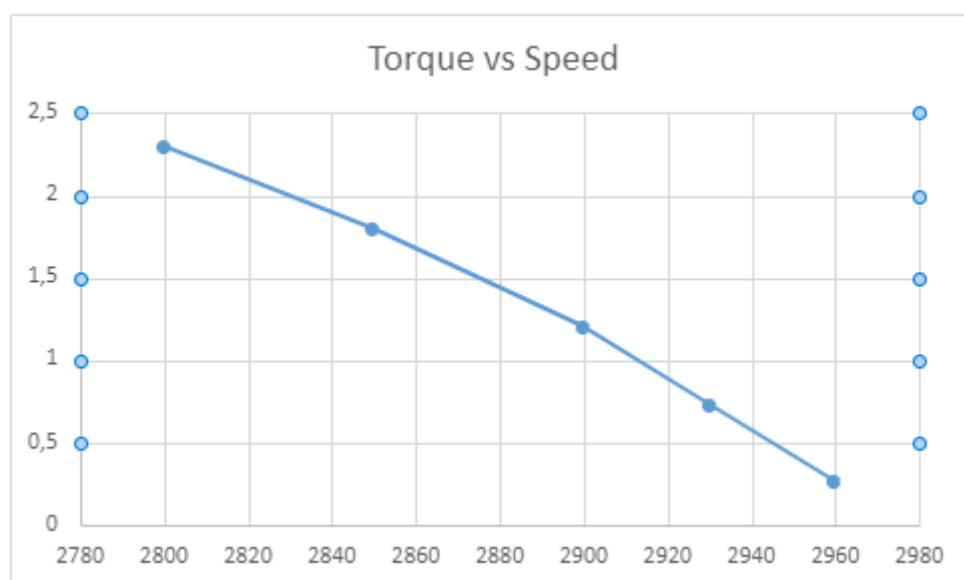
Image 5.1.43

5.2 detailed design(ese)

After previous research and with the help of the concepts created, we came to a detailed SCADA design.

The SCADA design contains the Smart-Grid that can be applied to Kleefsewaard and contains the energy generated by the wind turbines and solar panels. The local generated energy is used for industrial use and charging of electric cars and for auxiliary power ships.

With the help of the SFC it is possible to write a program for the soft PLC, with this it is possible to influence the battery storage. To achieve this, a busbar network is needed and various measuring equipment to measure for the generated / consumed energy, so it is then possible to calculate the balancing point.

5.2.1 SCADA

In the first set-up we mainly focused on the static load to recreate the households in Arnhem. And the dynamic load for IPKW. By turning on the created wind and solar profiles based on actual results at Arnhem we can see a clear image on how the GRID will perform.

On the image 5.2.2 we can see the SCADA layout with de different busbars. We have the integrated network which is the connection to the grid. Consumer I which we consider as energy going to IPKW, consumer II contains all the households in the region of Kleefsewaard. The four wind turbines and the 40.000 solar panels. The busbar in the end is for safety and maintenance reasons so the busbars can switch fase and always stay active.

Q1 is the isolator for the busbar 1 and Q2 is the Isolator for busbar 2. Q3 on the other hand is a cirquit breaker and is more there for the safety and that you cannot switch anything off while the circuitbreaker is on. The isolators 1 and 2 can't be on at the same time at the same panel.

On image   5.2.1 we can see the isolator and circuit breakers with the on/off buttons. Also added is the status light which will indicate if it's open or closed. In case an error appears while switching the warning light will light up. To reset the error the "reset error" button needs to be pressed.
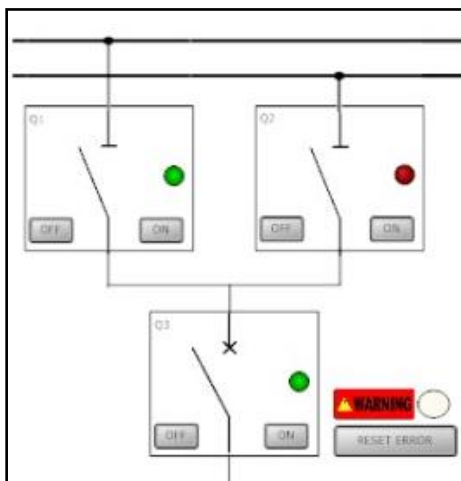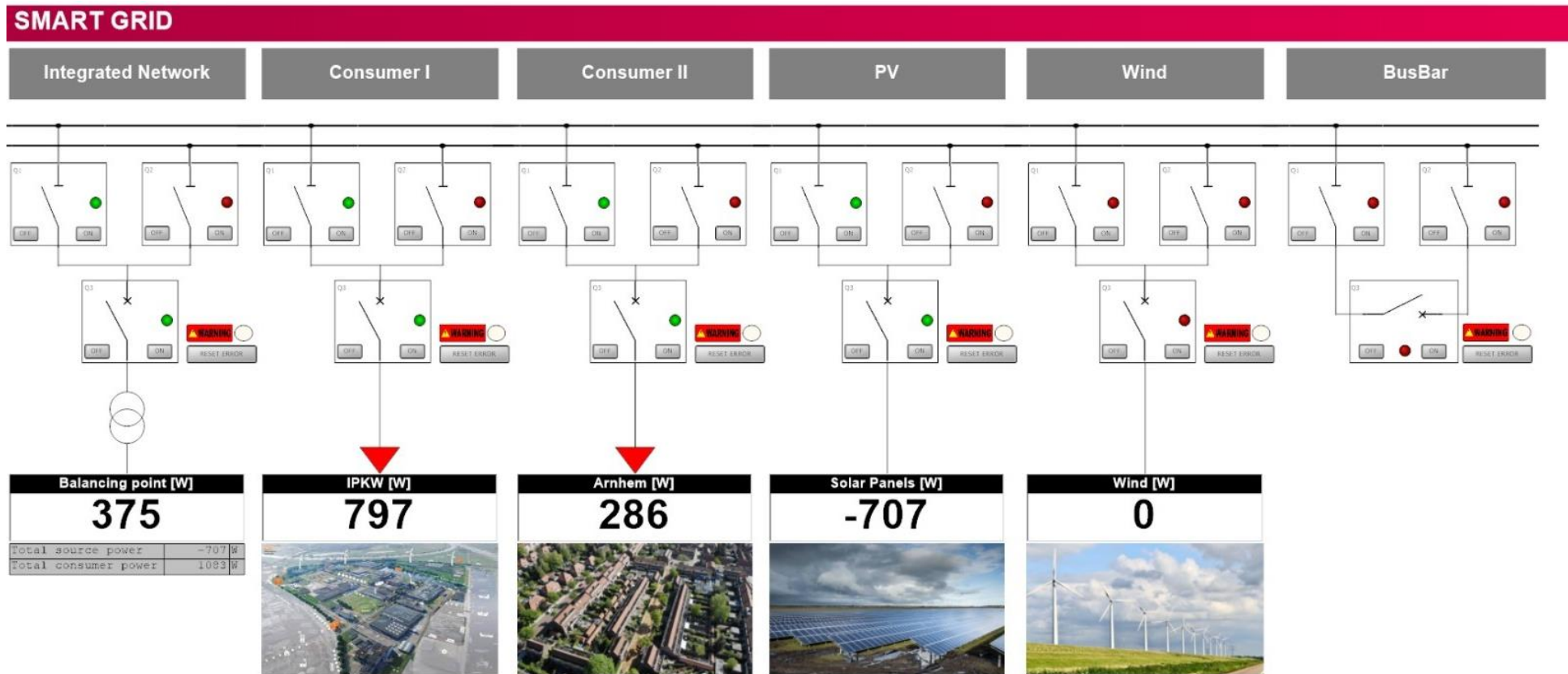

Image 5.2.1: SCADA isolators

Image 5.2.2: SCADA Viewer

5.2.2 PLC

At the SCADA there a some output value's visible. Most of the value's come directly from the quality meter who simply measure the values and are made visible in the SCADA.

There is a little bit of code currently behind the balancing point and to get the values for total source and consumer power. The values can be seen on image 5.2.3.
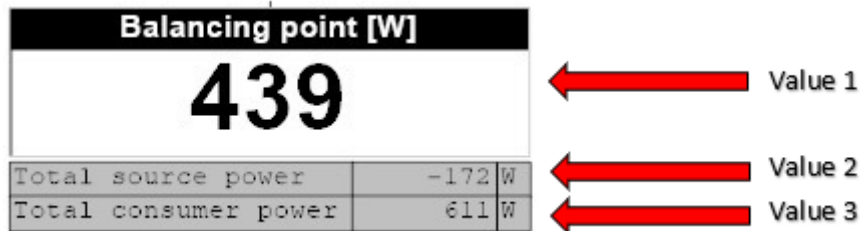

Image 5.2.3: SCADA Viewer

After adding all the VAR to the PLC program the PLC values can be added. In this case the value's are as follow:
Value 1 = PLC_Power_BP

Value 2 = PLC_Power_Total_Source

Value 3 = PLC_Power_Total_Consumer

The results of the calculations will be assigned to these value's so they can be used in the SCADA.

```
   (*****************************************************************
 *  BB7 Double busbar feeder CO3301-5R  Photovoltaic
 *****************************************************************)
BB7_Q71       AT %QX9.0100.00 : BOOL;          (* Close Isolator 1                  *)
BB7_Q71_O     AT %QX9.0100.01 : BOOL;          (* Open Isolator 1                   *)
BB7_Q72       AT %QX9.0100.02 : BOOL;          (* Close Isolator 2                  *)
BB7_Q72_O     AT %QX9.0100.03 : BOOL;          (* Open Isolator 2                   *)
BB7_Q73       AT %QX9.0100.04 : BOOL;          (* Close Circuit breaker 3           *)
BB7_Q73_O     AT %QX9.0100.05 : BOOL;          (* Open Circuit breaker 3            *)


   (*****************************************************************
 *  LUCAS-NÜLLE SCADA PLC
 *****************************************************************)

 (* Values *)
PLC_Power_BP            AT %QL2.0000 : LREAL;          (* Value 1, Power Transmission Line      *)
PLC_Power_Total_Source AT %QL2.0001 : LREAL;          (* Value 2 negative BP Power             *)
PLC_Power_Total_Consumer AT %QL2.0002 : LREAL;        (* Value 3 Power of Consumer I           *)
Derating_Wind_plc      AT %IL2.0003 : LREAL;          (* Derating Wind                         *)
Setpoint_LSC_plc       AT %IL2.0004 : LREAL;          (* Setpoint reactive power LSC Wind      *)
Setpoint_MSC_plc       AT %IL2.0005 : LREAL;          (* Setpoint reactive power MSC Wind      *)


 (* Digital I/O *)

PLC_Power_LED      AT %QX2.0000.00 : BOOL; (* D0 *)
(*PLC_Q2           AT %QX2.0000.02 : BOOL;*) (* Consumer II *)
PLC_Open_CB        AT %QX2.0000.03 : BOOL; (* D3 *)
PLC_Open_Isolators AT %QX2.0000.04 : BOOL; (* D4 *)
Drive_Error        AT %QX2.0000.05 : BOOL; (* Fault Drive *)
DFIG_Error         AT %QX2.0000.06 : BOOL; (* Fault DFIG  *)
PLC_Timer_OpenAll  AT %QX2.0000.07 : BOOL; (* D7 *)

PLC_static       AT %IX2.0000.08 : BOOL; (* Switch static load*)
(*PLC_dynamic    AT %IX2.0000.09 : BOOL; *)(* Switch dynamic load *)
Start_SG         AT %IX2.0000.10 : BOOL; (* All BB ON *)
Open_All         AT %IX2.0000.11 : BOOL; (* All BB OFF *)
```

Image 5.2.4 : Code

To get the total source power the wind and solar power coming from the quality meter needs to be added. And to get the total consumer power the consumer I and II need to be added.

```
PLC_Power_Total_Source :=  Wind_Power + Solar_Power;
PLC_Power_Total_Consumer := ConsumerI_Power + ConsumerII_Power;

if  PLC_Power_Total_Source < 0 then
PLC_Power_BP :=  PLC_Power_Total_Consumer + PLC_Power_Total_Source;
else
PLC_Power_BP :=  PLC_Power_Total_Consumer - PLC_Power_Total_Source;
end_if;
```

Image 5.2.5 : Code

When we get the total source and consumer power we can display the balancing point. Some thing that needs to keep in mind is that the source power can be positive and negative. So providing from the grid and giving to the grid.

In this case when the total source power is smaller then 0, so negative. The total consumer and total source power need to be added. And when the total source power is positive the total source power will be subtracted from the total consumer power.

At image 5.2.6 we can see the log of the balancing point with the total consumer and source power. With the log function it is easier to follow the different values of the balancing point and what it does when consumer and source are changing.
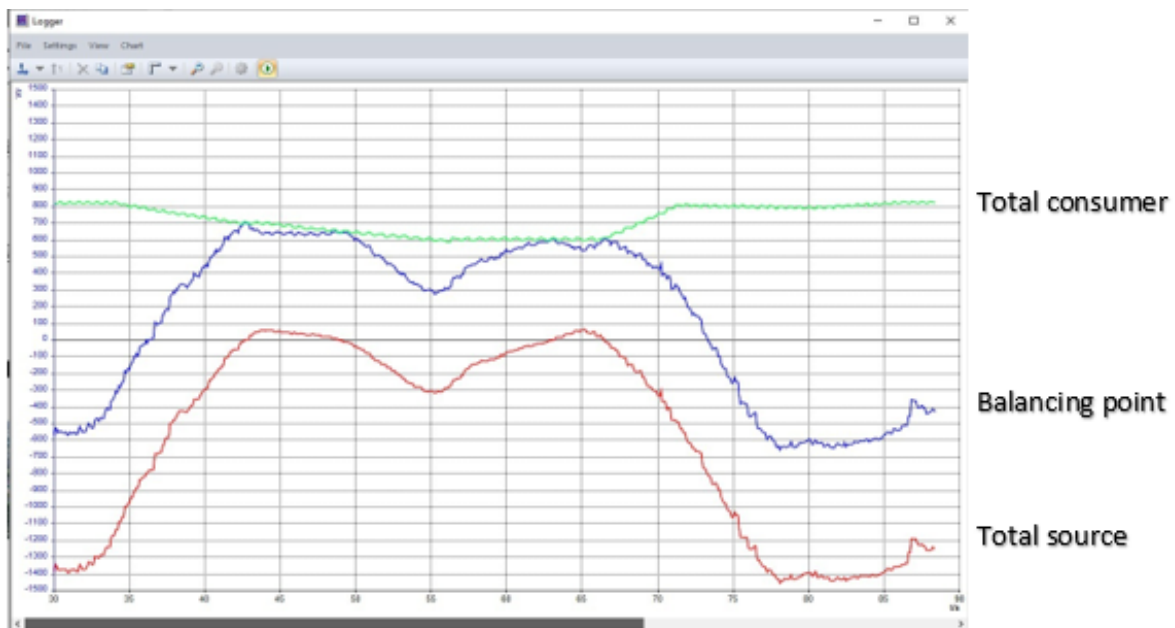

Image 5.2.6 : Logging

CONCLUSION IPS

For us as ipsers, this was certainly a project from which we learned a lot and will benefit a lot later on. At the beginning of the project, we really went to great lengths to understand Lucas Nulle's signs. We did this first on a small scale and then on a large scale.

We did this to go through each training module step by step and discuss what everyone thinks and share ideas.

After we understood the panels and understood the process, we started researching what exactly was being done at Koningspleij in Arnhem. We were able to find a lot about this after we summarized this with all specific values we could process this in the lucas null system.

To bring that into the lucas zero system, we put all values next to each other and played a profile of the Koningspleij. In this way we can describe the values to the real values.

All in all a nice project, especially very instructive, at times things went a bit stiff with what was specifically asked of us. In this communication we can learn something to put this down well in advance.

Appendix

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Plan of approach

1. Background information

The HAN stands for Hoge school Arnhem Nijmegen and is a university of applied science where the participants are students of. The school HAN also have a lot of research groups to help the students with establishing projects and teaching them core principals what they are going to use later in the workplace. the. The research group Sustainable Energy is a research group that is located at the HAN and that usually organize projects for students and find companies to work with.

The Smart grid project is one of those projects that is organized by the research group itself. This Project was given before but then only to semester 4 students. This makes it that a lot of devices that are in use with this project, the participants have not yet worked with them. The inspiration for this project is a solar field that is being built between the IPKW and the N325. The solar panels have an all-combined power of 12 MW. There is also a battery with a total capacity of 500 kWh. There are no stakeholders in this project. In this project the division of roles are a little bit closer to a teacher student set up, where the students or participants try to do tasks and when they get stuck, they can ask the teacher or client for further guidance.

That makes it that the client and the participants are working close together for the most part of this project. The commissioning organization is the research group Sustainable Energy from the HAN, the person that is responsible for this project is Patricia and that too is our client. When talking about contractors, those are the 4 IPS students and 2 ESE students participating as a team to this project. With 2 IPS coming from the international class and 2 IPS and 2 ESE coming from the Dutch class.

2. Project result

The SmartGrid project is meant to be an inspiration for the future real projects that are going to be constructed, one of them being under construction between the IPKW and N325 in Arnhem. Also, it is going to represent a variable resource of research upon this subject.

The main goal of the project is to create a simulated smart grid, using Lucas Nulle panels that can handle multiple inputs and outputs from the grid just as: photovoltaic panels, wind turbines, transmission lines, households (with their own PV systems), industrial loads with electrical machines and reactive power compensation systems.

The SMART requirements of the SmartGrid project are as follows:

- **S**pecific: The project group must create a stable, optimized, and efficient smart grid which can handle diverse inputs and outputs while the whole process can be supervised via a SCADA system.
- **M**easurable: The project weekly reports which are reviewed by the project coordinator and the feedback that the team will receive from both the expert and the coordinator.
- **A**chievable: The main goal of the team is to create a stable and efficient grid within the third semester. The goal is high, but with an effective team that works smart, and everybody sticks to the planning, the project will be realized.
- **R**elevant: Considering the complexity of the project, it would be impossible that the whole grid be completed by one person and that is why each member of the team will have to choose a part of the whole system and learn about it.
- **T**ime-bound: The courses about Lucas Nulle modules should be done before week 5 of the project. After that, the main object will be to create the final grid, and then to take the appropriate actions to make it as efficient as possible.

To maximize the efficiency of the project group, each member is going to make a part of the desk research and the practical connections of the grid. The IPS students are going to analyse and what it

would be best to connect and which way. Meanwhile, the ESE students will be involved in developing the software for the SCADA viewing system.

Of course, the system cannot be a perfect one, there are certain limitations that must be considered. The PV cells, the inverters, the electrical machines, and the reactive power compensation systems have certain power losses which would reduce the overall efficiency of the system. But the main concern should be to optimize the system in such manner that the power produced by the wind turbines and solar panels is going to be used while the surplus stored in the battery for times when the production is insufficient. In this way the whole system could be independent from the national grid system and the project sustainable.

In addition, the team should remain within their knowledge boundaries and not too far from it. Any complex system tends to be harder to operate and so the risk of accidents that could result in the destruction of equipment increases.

The final product of the SmartGrid team should be an efficient, independent from the grid, easy to operate and debug, smart grid system that would be able to have multiple inputs and outputs. Also, it is going to be easy to model and change in case the client needs to add or subtract certain features.

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3. Project activities

There are many tasks that must be performed before a result is achieved. This section makes clear which activities are and are being carried out to ultimately achieve the desired result.

First, it is ensured that knowledge is gained of the assignment (orientation) for this purpose, the documentation is read and what has been provided by the client is studied. Together with this documentation and a conversation with the client, it is clear what is expected. It is clear from this that in the first weeks of the project it is mainly about learning to work with the Lucas Nulle panels and figuring out what exactly a SmartGrid is. It is also important that a good project structure and division of tasks takes place quickly, for example, a planning is quickly set up in which each group member is placed with his task(s).

Before the desired result (Demonstration of a smart grid) is achieved, designs must be made for which crucial data is needed (Analysis). This data is obtained by performing desk research and field research, Desk research is information that can easily be found at home through the internet. The field research was gained by conducting experiments in the practical lab where the Lucas Nulle panels are located. Weekly reports are kept of this.

The assignments and experiments are divided into different chapters in labsoft. These assignments and experiments are performed in the classroom. The chapters.

- Professional photovoltaics
- Investigating bus bar systems
- Energy Management
- Wind power plants with DFIG
- Smart Grid
- SCADA designer tutorial

The experience gained during these experiments is later needed for the demonstration set-up. Short summaries of all these chapters are also made by the group so that it is easy to see what has been learned. A research report can be made from this. After the crucial data has been collected, the design of the concepts can be started. These can be drawings, but also calculations, connection diagrams and programming codes. Furthermore, it is important that the ESE and IPS students communicate well because some overlap of knowledge is needed, to realize this communication there is a weekly meeting. During meetings it becomes clear which concepts are proposed, these concepts are then developed into a final design. This design includes Schematics, drawings,

subsystems, PCB design and software code. Finally, a research report with recommendations is drawn up.

4. results

The following products will be delivered in the interim:
- Schedule for project and schedule chairman and note taker.
- Plan of approach.
- Desk/field research.
- Summary Professional photovoltaics.
- Summary Investigating busbar systems.
- Summary Energy Management.
- Summary Wind power plants with DFIG.
- Summary Smart Grid.
- Summary SCADA designer tutorial
- Concept designs.
- research report (PLC Code and Description) with recommendations.
- Demonstration Smart-Grid.
- Presentations.

5. Quality

We have received a clear project description for our project. We have discussed this with our manager. So, the quality and purpose of the Smart Grid project is completely clear to us as a project group.
Between the N325, the Kleefse Waard industrial park and the Nieuwe Haven, solar cells are being built that together have a capacity of approximately 10 MW.
To harmonize energy supply and demand, various parties are jointly experimenting with energy storage next to the solar field in the form of lithium iron phosphate batteries (LFP batteries) with a total capacity of 500 kWh. In neighbourhoods where a lot of solar energy is generated, the demand does not match the supply. Battery systems can temporarily store local energy so that it can be used locally later.
Before we really start working on the project, we will make various preparations to gain enough knowledge. And how to work with the different parts. That is why we are going to conduct a survey into the Smart Grid and its components. Everyone starts with a part and in the end we all discuss this together and everyone explains their topic clearly so that everyone understands what it is about.
After we have done research, we start working with the Lucas Nulle boards, these are simulation boards where we can make different circuits. This is easy for us because in theory we know roughly what is happening. But by using these boards we also see exactly what will happen in practice and so we can gather information and use this in our research.
In the Lucas Nulle part, IPS and ESE are separate from each other, this will be re-joined later in the project, but IPS is mainly concerned with the circuit and ESE is working with the plc.
One of our supervisors is going to send us another document with information that we must comply with. Here we must choose some subjects that we want to be judged on.

6. Project organisation

6.1 Division of tasks
In our group we have 3 three from IPS and two from ESE. We both have individual tasks during this project, but we all work together on the documentation. The group is divided as follows:
Ese:
Justin Volman and Fleur van der Kemp.
IPS:
Mihnea Predescu, Hasan Abobakr en Sander Schutte.

6.2 Communication
First, we created a group chat in which we mainly have all communication. If someone is bothered, has questions or any other matters, they can be mentioned immediately so everyone knows. So, we use WhatsApp as our "direct" contact in the group. We also use Microsoft Teams for sharing all files related to the project. We use Teams files because now we can all access these files anytime, we want. also, Patricia (commissioner) has full access.

6.3 Documenting weekly progress
After consultation with our client, we have agreed that every week we will record our experiences during the tests that we do for the project. We put all this information in one document. In this way we and Patricia get an overview of important discoveries and knowledge that we have gained.

6.4 Meetings
Meetings are an important part of a project. It is important that we as a group have a meeting moment every Monday morning. During this meeting there is a chairman who has prepared the agenda, and a secretary who notes everything that is said. To ensure that everyone has a turn, a meeting schedule has been drawn up in advance. This can be found in chapter 7 of the planning.
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7. Schedule

7.1 Creating a schedule
The project takes place in S3 and S4 (30-08-2021 / 21-12-2021). In this time we need to do different phases and deliver some documents. To get a clear view on the project we created a schedule with all the phases and deadlines. The schedule can be seen on the page below.
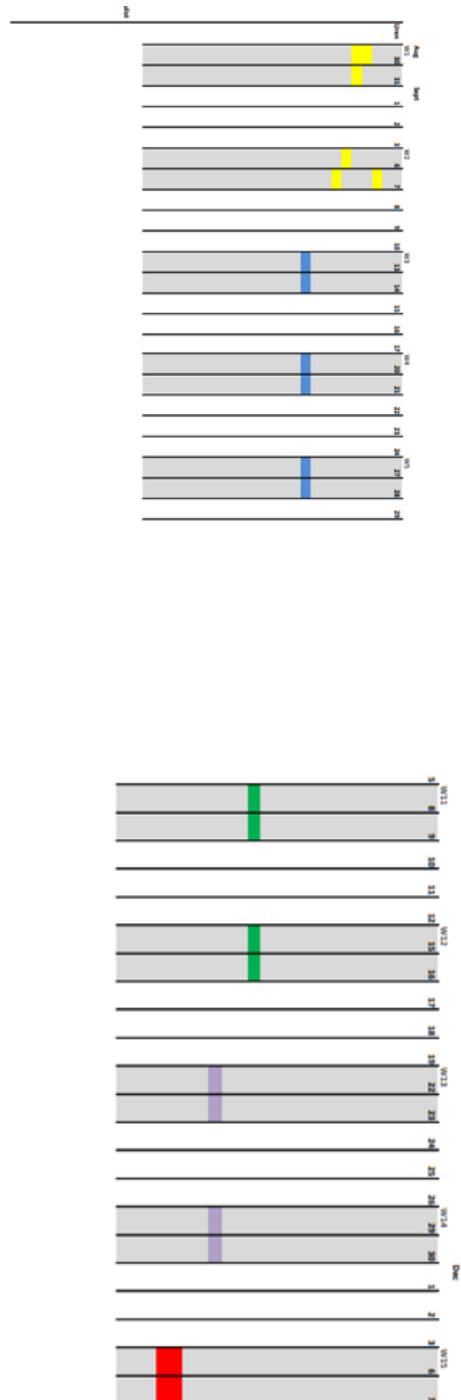
8. Project boundaries

Has it been sufficiently indicated to what extent the project continues ("length")?
As it was mentioned earlier, our project is "an inspiration for the future real projects that are going to be constructed". Therefore, it might be a bit hard to indicate "sufficiently" to what extend the whole project continues. For us, as engineering students, the length of this projects is mainly defined by the amount of knowledge we can possibly get about the Smart Grid and Lucas Nulle boards as well as SCADA system. It's clear for us that our final product of this project, should be an efficient, easy to operate and debugged demonstration set-up of a Smart Grid. As the roles and tasks are divided among team members and the system should be easy to model, team should have a clear vision on the concept of final design and reach a convenient bonding between hardware structure and software for SCADA system.
This demonstration set-up will be also equipped with research report. The report itself would be made from final design, which includes schematics, drawings, subsystems, PCB design and software code; weekly reports, which includes assignments and experiments; collected data and its analysis and recommendations.

Is it sufficiently clear what is not part of the project ("width")?
The real system which could be constructed and implemented in real life, based on our demonstration, would have loses which would not be as negligible as they would be in our demonstration. Furthermore, some of those loses and their behaviour might be unknown for us. Therefore, as we need to stay within our knowledge boundaries, some loses and limitations would be just considered as they are, without going into more deep explanations.
Also, the project itself involves different parts and aspects, new equipment, skills, and information, which means that some bits and piece might be hard and complex. Therefore it's so important to be focused on a main goal, set up a particular frame and not go into unnecessary details.

Is it clear what conditions must be met for the project to succeed?
Although, some parts of the project might be completely new to our group, some basic rules must be followed to reach successes, such as: clear documentation maintenance, high communication level inside our team and good timing. However, for this project, we also need to make sure that we can carry out both desk research and field research to make worthy research report. This is very important to provide a clear vision for IPS and ESE students, for them, working in cooperation to come-up with a concept and turn it into the final design.