Bachelor thesis

Optimization of energy storage use for solar applications

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Abstract

Energy storage systems is very useful to use in solar panel systems to save money, but also to be more environment-friendly. The project was given by the solar energy company Perpetuum Automobile (PPAM) and the project is for their customer, the condominium compound Ekoxen. The task is to make a energy regulation for Ekoxen's energy storage so they can save more money. The energy storage primary task is to shave the top-peaks of the consumption for Ekoxen. Which means that the battery will supply the household instead for the three-phase grid. This will make the electric bill for Ekoxen cheaper. The simulation/analysis of the energy regulation is done in a spreadsheet tool, where one part works as a Time-of-Use program and the other work as a modbus feature. Time-of-Use is a web-based program for PV systems with battery storage, where time-periods can be set to affect the battery behavior. The modbus feature simulates a system where an algorithm can be implemented. The results will show that the time-periods for charging the battery with the Time-of-Use program needs to be changed two times per year. One time for the summer months and a second time for the rest of the months. The results will also show that the modbus feature is better on peak shaving than the time-of-use program.
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<td>Perpetuum Automobile</td>
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<tr>
<td>PV</td>
<td>Photovoltaic</td>
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<td>PVsyst</td>
<td>Simulation program for solar panel systems</td>
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<td>t</td>
<td>Time in hours</td>
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<td>$P_{\text{Three-phase grid},t}$</td>
<td>Power from and to the three-phase grid in kW at hour t</td>
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<td>$E_{\text{Bat}}^{\text{min}}$</td>
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<td>Maximum battery capacity in kWh</td>
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<td>SoC</td>
<td>State of charge</td>
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<td>$\alpha_t$</td>
<td>Variable for charging (1) or discharging (-1) the battery at hour t</td>
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<td>$\eta$</td>
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<td>$k$</td>
<td>Coefficient for discharge/charge power</td>
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1. Introduction

A problem with solar energy systems is that the consumption peak during 24h at facilities does not coincide with the maximum radiation from the sun. This leads to excess of energy during the day and bought expensive power during night. This project will investigate how to make a solar energy system to be more effective and cheaper by using energy storage. The solar energy system that is going to be streamlined are both connected to the grid and battery. The main goal will be to lower the power peaks from the three-phase grid, the highest peak during one hour for a month defines the monthly fixed tariff. This is the main cost in the electricity bill every month for those who have a main fuse bigger than 80A. The goal will then result in a more cost-effective PV system. Another aspect is that the cost of taking energy from the three-phase grid often depends on which time of the day it is done.

The batteries are often charged to their maximum capacity during day-time by the solar panels and during night-time are the energy often discharged from the batteries. The excess energy that is produced during day-time are uploaded to the grid. To make this less expensive a regulation of the energy storage needs to be done, so that the batteries can be used when the consumption from households is at its peak.

The report will explain a spreadsheet tool that can be used to see how much money that can be saved if the regulation is used.

1.1. Motivation

As mentioned in the introduction the main cost in the electricity bill is defined by high consumption peaks. By discharging the batteries at peak load each day the electricity bill will be reduced.

![Power consumption during 24 h](image)

*Figure 1. Power consumption for a household during 24 hours from three-phase grid.*
Figure 1 represents the power consumption for a household for 24 hours. The blue line can be seen as the limit for where the batteries should discharge to lower the consumption from the three-phase grid. The maximum power consumption reduction at the three-phase grid is limited to the max discharge power from the batteries unless there is excess solar power. By regulating this, so that the peak load for each month is reduced by the discharge power from the batteries then the cost for the customer will be lower.

1.2. Purpose

We have been interested in solar energy systems for a long time and we think it is valuable that we can use the sun as renewable energy source. This project will give us an opportunity to get an insight to the solar energy industry. How we go from solar panels to charging households. The project will give us the bigger picture and make us go into more details about solar energy systems than what we have done before.

A good energy regulation for a solar panel system is important to have. It can make the total cost for a solar panel system to be lower and that can convince a customer to buy a solar panel system.

1.3. Problems

The topic for this work is to study how to do an energy regulation when using an energy storage in a solar panel system. The project will be done for the condominium compound Ekoxen. The system will be connected to the three-phase grid, to the solar panels and to the energy storage. The main goal will be to lower the power peaks from the three-phase grid. The power peak during one hour for each month is multiplied with 95,2 SEK and this is the main cost for the customer (E. ON Energidistribution AB. (2018)). The goal will then result in a more cost-effective PV system. An analysis of the energy flow will be done in a spreadsheet tool.

This paper will handle the following questions.

- How will the energy storage be regulated?
- How will the energy / economic analysis in the spreadsheet tool be done?

The spreadsheet tool will contain the solar production profile and the energy consumption profile for the condominium compound Ekoxen. With these profiles will there be two different scenarios. One analysis of when the solar panel system is connected to a battery and one analysis without a battery.
1.4. Limitations

PPAM uses inverters to and from their energy storage, to transform DC to AC and vice versa. The inverters who are used for the batteries are three Sunny Island battery inverters. The inverters have a network-based communication protocol called modbus that can be used with programmable logic controllers (PLCs). The algorithm that will be presented in this project can be implemented in these Sunny Island inverters in the future. This report will be limited to condominium compound Ekoxen.
2. Background
The project was given from the company PPAM Solkraft, which is a Swedish company in the solar energy industry. They install solar energy systems for both private customers and for companies all around the world. Their latest project was about duplex photovoltaic panels which is a solar panel that stands on its edge and has bifacial PV cells.

The reason to why they want a solution of regulating when to discharge and charge the battery is simply to save money for their customers. As mentioned before the goal will be to lower the power peaks from the three-phase grid. PPAM wants this regulation implemented in a spreadsheet tool to show their customers that it is an advantage to use batteries for a solar panel system.
3. Theory

In the making of a regulation for a systems energy storage, a lot of technical information needs to be known. Information about how the battery is connected to the solar panel system, generally all parts that are connected to the system needs to be known. Which kind of ways that can be used to regulate a battery does also need to be know, hardware or software regulation.

3.1 Basic concept

Solar panel systems are often connected to the three-phase grid. The problems that can occur when solar panel systems are connected to the three-phase grid is that the solar panels can produce more power than the main fuse that is connected to the three-phase grid can handle. One solution has then been that the solar panels also can be connected to batteries and save the excess energy. Then use the energy storage for optimization of the maximum bought power per month by discharging energy storage during peak load and recharging it during off-peak times. Optimization of the charge and discharge for the batteries would also reduce the subscription cost due to lower cost related to reduced main fuse.

![Power during 24 h](image)

*Figure 2. Example of saved energy, power consumption and excess energy during 24h*

The yellow curve in figure 2 represents the saved energy during the day, i.e. the solar power that has been used in the household. For optimizations purposes it is better to store the excess and use it later at night time, at peak load which usually is around 17:00 - 21:00. The red
curve represents the power consumption and as seen in the example graph the peak load is at around 20:00. One purpose with the energy storage regulation is to get smaller main fuses, but with smaller main fuses there would most certainly be a loss of excess energy because it cannot be dispatched to the grid. If two cables are installed from the transformer to the main central one solution would be to install a bigger main fuse for the electricity that is produced and a smaller one for the energy consumption, because it is the energy consumptions main fuse that the price is based on. But usually there is only one cable connected and therefore only one main fuse. An energy storage system needs to be dimensioned to manage the maximum excess energy that is produced during one day of the year, beyond the main fuse limits. Every evening/night can the energy storage be consumed, in that way the energy storage can be minimized.

Another good aspect of having solar panels is that an additional revenue is added in form of tax reduction for the energy that is sold. Although there is a limit to this revenue. If the sold energy exceeds 30000 kWh over one year or if the sold energy is more than the consumption of the facility for one year then the revenue is excluded. By installing an energy storage both energy and money can be saved by charging the energy storage with solar power.

Figure 3 represents simplified block diagram of a microgrid with PV panels, energy storage and three-phase grid. A simplified microgrid to get an understanding of how the system is structured. The inverter from the batteries needs to get information from the energy meter that is connected to the three-phase grid to make a good energy storage regulation. The information can be how much power the load needs, how much energy that flows from the PV panels and from the three-phase grid.

S.J. Chiang, K.T CHang and C.Y Yen introduces a residential PV energy storage system. The power from the PV panels is controlled by a dc-de converter and then transferred to a battery energy storage. To manage the power from PV panels, batteries and the three-phase grid they
look at a pattern that considers the load characteristic of the residential. The system noticing the pattern and then chooses an operation mode so that the power from the PV panels, the three-phase grid and the batteries are managed in the most cost-efficient way. (Chiang, Chang & Yen 1998)

3.2 Sunlight RES OPzS Battery

Information about the batteries behavior needs to be known to make a good energy regulation. The values that are often checked are for an example the state of charge value and the power flow, which will be explained.

3.2.1 State of charge (SoC)

To regulate a battery’s discharge and charge capacity some important aspect needs to be considered such as the state of charge criteria. The state of charge corresponds to how much the batteries are loaded, 100% SoC corresponds to a full loaded battery and so on. The way of then using this for regulating a battery is to have limit values for SoC. These limitations are set by what capacity the batteries have and by external references. For an example, the external references can be the required energy for a household. If the desired energy for a household is achieved, the remaining energy from the solar panels goes to charging the battery (Krishan, Mishra & Verma, 2017).

3.2.2 Power flow

Power flow is the power that the battery is charged and discharged with. This value depends on the battery capacity, the ambient temperature and the number of cycles the battery has left. The maximum power flow is often not the optimal power flow to use. It can harm the batteries lifetime. To make a good energy regulation of an energy storage must a consideration of how much stored energy that can be spent so there is enough for each hour.

3.2.3 Battery behavior

The battery that are used for Ekoxen's solar panel system follows the SMA inverter criteria. The criteria are most made for making the battery safe.

The criteria are the self consumption, state of charge, battery-backup function and deep discharge protection. The self consumption for the battery depends on how much solar energy it gets during each day and to higher consumption in winter and lower consumption in the summer in the northern hemisphere. The self consumption is the accessible energy in the battery. For lead-acid batteries can the self consumption for the shortest day of sun hours be between 65% - 100% SoC. During the longest day can the own consumption be between 45% - 100% SoC. The battery-backup function has the task to help the solar panels when there is not enough of solar energy. The battery will then provide energy to the system. The battery-backup function goes on at 15% to 60% during the winter season and 15% to 40% during the summer season. The battery has deep discharge protection, if the battery SoC is between 10% to 15% during both winter season and summer season, the battery will go into this state. Deep discharging can damage the battery cells and make the life-time for the battery shorter. (SMA Solar Technology, version 5)
The losses of charging and discharging the battery is also important. The losses happens when the energy goes thru the inverter that is before the battery. In the Sunny Island inverter is the efficiency 95,8%. That means that the energy flow to the battery will lose 4,2% of its energy (SMA Solar Technology, version 2.1.).

### 3.3 Regulation techniques

Different ways to regulate the energy will be explained. Energy that goes thru the solar panel system to make it more cost-effective. The regulation is often done in a programmable inverter that is connected to the solar panels. Later on will there be a discussion on how the regulation will be done.

#### 3.3.1 Power Limiting Control (PLC)

One way of controlling the active power that comes from the solar panels is to have a limit value for the total energy and by comparing it with the actual energy that comes from the solar panels. This limitation is set by own choice. If the output voltage from the solar panels are lower than the limit value, then the PV voltage from solar panels will be set to the limit value. If the output voltage is higher than the limit value, then the voltage from the solar panels will be set to the difference between the output voltage minus the difference between the MPP value for one PV array and the MPP value for the second PV array (Blaabjerg, Sangwongwanich & Yang, 2017).

Maximum Power Point (MPP) corresponds to the maximum power that the solar panels can give at their output. This value is very important to know when building solar panel plants (Bhatt, Manjrekar & Sahu, 2017).

#### 3.3.2 Power Ramp-Rate Control (PRRC)

The output power from the solar panels can also be controlled by watching how the output power increases/decreases and then take out the derivative of the curve. In this case does it also need to have a reference value which can correspond to the maximum power derivation. These two derivations can then be compared and make a regulation for the energy that goes from the solar panels. If the derivation of the output power is lower than the reference value, the output voltage from the PV panels will be set to the MPP voltage for the solar panels, else will the output voltage be set to the difference between the output voltage minus the difference between the MPP voltage and the output voltage which the deviations of the power corresponds to (Blaabjerg et,l, 2017).

#### 3.3.3 Power Reserve Control (PRC)

The Power Reserve Control is like the Power Limiting Control but with some changes. The reference value for this case will be the difference between the available power from the solar panel and the power reserve. The power reserve is the ratio between the MPP and a fixed value that can be changed by chosen specification. To calculate the available power from the solar panels, the solar irradiance have to be measured and approximations of what the solar panels can generate at their output (Blaabjerg et,l, 2017).
3.3.4 Mean value
One way of controlling the energy flow in the solar panel system is to make the consumption-curve for a household look like the average load curve. This technique is very dependable on what power flow the battery uses. The consumption curve would get more symmetric with this strategy and that will result in lowering the top-peaks (Rahimi, Zarghami, Vaziri and Vadhva, 2013).

3.3.5 Time-of-Use
There are many different ways to control the batteries charge and discharge mode. The most recent strategy is by controlling it online. Time-of-use is a net-based energy optimization tool which controls how the energy flow will go depending on what the energy cost from the three-phase grid is. If the energy cost from the three-phase grid is cheap, the household / the battery will be charged from the three-phase grid. The energy costs from the three-phase grid are set in a tariff and can be divided into many different levels, but the most common is to have three different costs. Where these three costs are for top-peak, shoulder-peak and off-peaks. The program is connected to the inverters that are in the system.

Time-of-use is often used when the solar panel system is connected to a energy storage. The time-of-use program does then have one more specification that it depends on which is the power flow for charging the battery. This part of the Time-of-use program is called “Battery Charging Window”. That is used by setting different power flows for different times a day. To be clear, this is only done when charging the battery, when discharging the “Battery Charging Window” is left unspecified. If the tariff and the “Battery Charging Window” are configured for the same time period, the “Battery Charging Window” is prioritized. (SMA Solar Technology, version 11)

3.4 Modbus
Modbus is a programmable logic controller system and it is often used for energy management for households. Modbus can be found in PV systems, where it controls the systems inverters. The inverters parameters can be used as inputs to modbus and in modbus can a regulation of the parameters be done.

3.5 Economical parameters
There are many economical parameters that needs to be considered when it comes to electricity- and energy flow. The energy flow from and to the three-phase grid are split into three different parts. When buying and selling energy from the three-phase grid there is costs from the grid owner, costs that comes from the energy supplier and earnings from the company that buys the sold energy.

3.5.1 Grid owner
The three-phase grid owner is the ones that owns and maintains the transmission lines. The three-phase grid owner is the ones that distributes the energy from the energy producer to the consumer. The three-phase grid owner takes a cost for the chosen subscription, that cost is
split equally over the year. The subscription cost is based on the size of the main fuse. To transmit the energy from the power source to a household, a transfer cost is added. The transfer cost is based on how much energy that is used. The last cost is based on the maximum power that has been used at one specific time. The power is measured hourly and the highest power measured for one month is multiplied with a constant. This cost only occur to those who have a main fuse that is bigger than 63 A. The grid owner cannot be chosen (E.ON Energilösningar, 2018).

3.5.2 Energy supplier
The energy supplier buys energy from the energy producer companies and is responsible that the right amount money is paid for the right amount of energy, often thru the concept take first pay later. The energy supplier takes out a cost for the total energy used. The cost can either be variable or fixed and often varies during day and night time based on consumption. The cost is based on a base cost which is fixed or variable and this is the main part of the cost. An electrical certificate cost and a mark-up cost is also included. The law about electrical certificate is supposed to favor the electrical production from renewable sources. The mark-up costs are for the administrative parts. There is also taxes that needs to be paid on every consumed kWh (E. ON Energilösningar, 2017).

3.6 Description of PVsyst
To create a regulation for the energy storage, the system need to know which parameters that should be focused on and information about the facility's energy-feed needs to be known. To find the solar energy production profile a program called PVsyst can be used. PVsyst is a photovoltaic software program for sizing and data analysis of PV systems. It can handle grid-connected and stand-alone PV systems (PVsyst).

PVsyst is a well-known simulation program for solar panel systems. A lot of researchers have used it to get a good overview of their solar panel systems. R.A. Shalwala and J.A.M Bleijs used the PVsyst program when they determined the ability of grid-connected photovoltaic systems in Saudi Arabia (Bleijs & Shalwala, 2010).

Hasimah, Khalid and Mohammad compared the PVsyst program with another simulation program for solar panel system which is called RETScreen. They tested the simulation programs on four different solar cells and measured important values. The most important value to measure were how much energy the solar panel system gave at their output. There was a difference of 2% between the simulation programs for that value (Hasimah, Khalid & Mohammad, 2009).

3.7 Spreadsheet tool
To make a spreadsheet tool for how much profit the customer gets if they use a regulation of the energy storage, some calculations and parameters need to be known. The basic things that needs to know is the consumption and production profiles, battery capacity and solar panels. Consumption power and solar power for each hour over the year will be listed in the spreadsheet tool. The consumption is based on last year consumption from the condominium compound Ekoxen and the solar power is simulated from PVsyst.
4. Method
The choice of how to regulate an energy storage has been based on how the consumption and the solar production is. The corresponding profiles will be discussed in the next chapter.

4.1 Profiles
The solar panel system that will be analyzed in this project is located in Norrkoping at the condominium compound Ekoxen estate. It is both connected to the three-phase grid and to an energy storage system. They will have 288 pieces of PPAM Paladium PV modules, were each provides 325 W and costs 15,26 SEK / W. The energy storage system they have has a battery capacity at 203 kWh and the max charge / discharge for those are 18 kW. The cost per kWh for the batteries are 5,76 SEK / Wh. The fuse to the three-phase grid is at 100 A, which corresponds to a limit power value at 69 kW.

![Figure 4. A satellite picture of condominium compound Ekoxen (Google Earth).](image)

To make a economical regulation of the solar panel system the consumption- and production profile needs to be known. The production profile corresponded to how much energy the solar panels gave out. This profile was found by using the program PVsyst. This profile was simulated by PPAM and in that simulation was it 80 PPAM Paladium PV modules. Therefore, the production values were multiplied with 3,6, because Ekoxen had 288 solar panels. They made a simulation for 80 PV modules to make a general estimation.
The consumption profile was given from EON, which is the three-phase-net owner for Ekoxen. The profile corresponds to how much energy the facility consumes from the three-phase grid. The profile includes hour values between the year 2017-2018. The values in the profiles is shown below and compared to each other.

![Consumption profile for Ekoxen in July](chart.png)

Figure 5. The consumption for Ekoxen during 24 hours in July.

Figure 5 represents the consumption for a day in July. The consumption during night-time is low and then it gradually goes up. During the evening, around 5:00 PM - 9:00 PM is the consumption at its highest value.
Figure 6. The solar energy production during 24 hours in July.

The solar power is at the highest peak during daytime, according to figure 6 it is around 57 kW. It gives out energy during a long time because of that the number of sun hours is higher in July.

A comparison between the consumption and the production diagram from July shows that it will be a lot of excess energy during the day. This excess energy can either go to the three-phase grid or to an energy storage system. To lower the energy-cost for every month, is it more advantageous to save the energy in the energy storage system than selling it to the three-phase grid. The excess power is around 41 kW during peak sun time.
In January it is seen that the consumption is higher than it was in July. That is because Ekoxen use the three-phase grid to warm up the compound. This diagram is tho similar to the consumption diagram in July, the peaks still occur at approximately the same time. It is still around 5:00 PM - 9:00 PM.
There is a big difference between this two months is the amount of solar energy production. In a day in January it is not more than 4 kW. When it comes to this certain time of the year it is important to have a charged energy storage system to lower the top peaks at the three-phase grid.
The maximum power consumption per month is at least above 40 kW. That would make a cost around (> 4760 SEK for each month and that is the value that makes the electric bill more expensive.

![All consumption-peaks during 12 months](image)

*Figure 10. The consumption top-peaks and off-peaks for each hour for 12 months.*

The peaks and the off-peaks can sometimes come randomly, at different times. As an example, in figure 10 a peak at 3:00 AM occur. As seen most of the peaks are around 4:00 PM - 10:00 PM and that the off-peaks are at the time between 11:00 PM - 6:00 AM. When the top-peaks occur would it be most useful to have a energy storage system to discharge, to lower the energy cost.

### 4.2 Energy and cost analysis in the spreadsheet tool

In the spreadsheet tool were two different scenarios made. One scenario where only the solar panel production and the consumption were considered and another scenario where the battery, solar panel production and the consumption were considered.

For each scenario a calculation of the total consumption, total solar panel production, total overflow and the total energy from the three-phase were calculated for every month. Also, calculation of the maximum power during one hour was for every production was made.

How much money the costumer would save for this solar panel system and what the total cost would be needed to be calculated, with and without an energy storage.

To make a good structure for doing this analysis, three different sheets in the spreadsheet tool were made. The first two sheets contained all the hour values for the profiles, for the overflow and for the energy at the three-phase grid. In one of those sheets the battery capacity for each hour was added. In the third sheet were all calculations made, the total energy calculations and the cost calculations that was explained above.
Table 1. Economical values for the condominium compound Ekoxen.

In the economic analysis was two separate analysis considered. One analysis of what the total cost would be of the energy flow and a second analysis of how much money Ekoxen would save. Remember that these calculations only calculate the costs for the energy flow.

4.2.1 Calculations for the total cost of the energy flow

For the total cost analysis, a calculation for the transmission cost for the energy supplier and for the grid owner was made for each month. The cost for the maximum power, the energy tax and the sold electricity for each month was also calculated. The subscription cost was also taken to account. The results from the formulas are in SEK.
The formula that was used to calculate the transmission cost for the energy supplier was:

\[ T_{\text{cost, energy supplier, month}} = P_{\text{three-phase grid, } t} \times (E_{\text{cost, April-Mars, } t} + I_{\text{certificate}} + M_{\text{ark cost}}) \times \text{VAT} \]  

(4.2.1)

\( P_{\text{three-phase grid, } t} \) corresponds to the power when only using solar panels and in the other scenario does it correspond to the power when using battery and the solar panels.

The transmission cost for the grid owner was calculated as:

\[ T_{\text{cost, Gridowner, month}} = P_{\text{three-phase grid, } t} \times T_{\text{cost, Gridowner}} \times \text{VAT} \]  

(4.2.2)

The cost for the maximum brought power was calculated as:

\[ P_{\text{max cost, month}} = P_{\text{max, month}} \times P_{\text{cost}} \times \text{VAT} \]  

(4.2.3)

The total energy tax for each month was calculated as:

\[ E_{\text{tax, month}} = P_{\text{three-phase grid, } t} \times E_{\text{tax}} \times \text{VAT} \]  

(4.2.4)

The estimation of the amount of sold electricity was calculated as:

\[ I_{\text{sold, month}} = P_{\text{overflow, } t} \times (T_{\text{ax reduction}} + (I_{\text{sold}} \times \text{VAT} \ ) + (P_{\text{Solar, } t} \times I_{\text{certificate, Sold}}) \]  

(4.2.5)

The total cost was then:

\[ T_{\text{ot cost, month}} = (Sub_{\text{cost}} + T_{\text{cost, energy supplier, month}} + T_{\text{cost, gridowner, month}} + P_{\text{max cost, month}} + E_{\text{tax}} - I_{\text{sold, month}}) \]  

(4.2.6)

### 4.2.2 Calculations of total saved money by using solar energy

In the second analysis were calculations for the transmission cost for the energy supplier and for the grid owner made. The cost for the maximum power, the energy tax and the sold electricity was also considered. These calculations were made for each month.

The formula used for calculating the transmission cost for the energy supplier was:

\[ T_{\text{cost, energy supplier, month}} = (P_{\text{Solar, } t} - P_{\text{overflow, } t}) \times (E_{\text{cost, April-Mars, } t} + I_{\text{certificate}} + M_{\text{ark cost}}) \times \text{VAT} \]  

(4.2.7)

The value of \( E_{\text{cost, April-Mars, } t} \) depends on the month.

The formula for the transmission cost to the three-phase grid owner was:

\[ T_{\text{cost, Gridowner, month}} = (P_{\text{Solar, } t} - P_{\text{overflow, } t}) \times T_{\text{cost, Gridowner}} \times \text{VAT} \]  

(4.2.8)
The subtraction between $P_{\text{Solar},t}$ and $P_{\text{overflow},t}$ corresponds to the power from and to the three-phase grid. The value of $P_{\text{overflow},t}$ depends on if the overflow is used to charge the battery or not.

The formula used for calculating the cost of the maximum bought power was:

$$P_{\text{cost, month}}^\text{max} = (P_{\text{max, month, Load}}^\text{max} - P_{\text{max, month, three-phase grid}}^\text{max}) \times P_{\text{cost}}^\text{max} \times \text{VAT}$$

(4.2.9)

The formula used to calculate the cost for the energy tax was:

$$E_{\text{tax, month}} = (P_{\text{Solar},t} - P_{\text{overflow},t}) \times E_{\text{tax}} \times \text{VAT}$$

(4.2.10)

Formula for the sold electricity cost was:

$$I_{\text{sold, month}} = P_{\text{overflow},t} \times (T_{\text{ax, reduction}} + (I_{\text{Sold}} \times \text{VAT}) + (P_{\text{Solar},t} \times I_{\text{certificate}})$$

(4.2.11)

The total saved money was then:

$$T_{\text{ saved, month}} = T_{\text{cost, energy supplier, month}} + T_{\text{cost, Gridowner, month}} + P_{\text{cost, month}}^\text{max} \times E_{\text{tax}} + I_{\text{sold, month}}$$

(4.2.12)

$$\text{Battery}^\text{saved cost, month} = (T_{\text{Total cost, month, solar energy}} - T_{\text{Total cost, month, solar energy + saved battery energy}}) \times (T_{\text{Total saved money, month, solar energy + saved battery energy}} - T_{\text{Total saved money, month, solar energy}}$$

(4.2.13)

One more calculation had to be done when the battery was taken to account. Which was how much Ekoxen would save by saving energy in a battery for their solar panel system. The equation can be seen in 4.2.13.

**4.3 Understanding PPAMs battery behavior in Time-of-Use**

The time-of-use testing was made on PPAMs batteries. Different types of energy cost for different time-intervals were tested. The battery charging diagram for these electrical tariffs corresponds to SoC measurements for each electrical tariff. These tests were done to get a better understanding of the battery behavior. The tests were done in April 2018.

In the first test was the off-peak set to 0.25, the shoulder-peak to 0.3 and the top-peak to 0.31 SEK. One more shoulder-peak was set to 0.27 SEK to let the battery charge. These values are only symbolic values of when to discharge or charge the battery. The feed-in tariff was 0.5 SEK for PPAM. Under the first test was the time-window for battery charging with power flow of 7 kW.
Figure 11. Electrical tariff from sunny portal for PPAMs energy storage with off-peak 0.25, top-peak 0.31 and shoulder-peak 0.3 and 0.27 SEK. Test one.

The red color in the time-intervals in figure 11 corresponds to a time-interval were the energy from the three-phase grid is expensive. The green color corresponds to a time-interval were the energy from the three-phase grid is cheap. During the green interval is the battery allowed to be charged, but not during the red intervals. With that said, the system allows the battery to be charged from the grid, according to this the batteries would charge during the night. The time-control for charging the battery was set during the green time-intervals for each test.

Figure 12. State of charge-diagram for PPAMs batteries for the electrical tariff in figure 11.

In the electrical tariff in figure 11 was the off-peak set between 12:00 AM and 6:00 AM, this was done because the battery had to be charged during the night. Accordingly, to figure 12 the battery did not do anything during that time-interval. Same thing happened for the off-peak between 8:00 AM and 11:00 AM. The battery did only charge between 11:30 AM and 7:00 PM. The battery should not have charged between 11:00 AM and 1:00 PM, but it
did. One reason to why it charged during this time-interval can be that it was a lot of overflow during this interval. The battery charged with the overflow instead of following the electrical tariff.

In the second test was different cost for the peaks used. In this case were the off-peak 0.25 SEK, the shoulder peak 0.4 SEK and the top-peak 0.5 SEK. Still in the ratio of PPAMs feed-in cost.

![Figure 13. Electrical tariff for PPAMs energy storage with the cost off-peak 0.25, shoulder-peak 0.4 and the top-peak 0.5 SEK. Test two.](image)

In the second test was the values closer to the feed-in tariff, to check if the power flow would increase. This test had more discharging intervals.

![Figure 14. State of Charge-diagram for PPAMs batteries for the electrical tariff in figure 13.](image)
In the second test did the battery have around 68% SoC in the beginning, that is because the battery discharged the night before from a much higher SoC value. The battery does not charge at the morning although it was set a charging interval between 12:00 AM and 6:00 AM, instead it discharges to 65%. In the time-interval between 6:00 AM and 8:00 AM should the battery be discharging, but according to the SoC-diagram it is charging.

In the third test was peak-costs that were above the feed-in tariff used. The off-peak cost was 0.25, shoulder-peak cost was 0.9 and the top-peak cost was 1.0 SEK.

![Figure 15. Electrical tariff for PPAMs energy storage with the cost off-peak 0.25, shoulder-peak 0.9 and the top-peak 1.0 SEK. Test three.](image1)

Using energy-costs above the feed-in tariff should result in a higher power flow for the battery.

![Figure 16. State of charge-diagram for PPAMs batteries for the electrical tariff in figure 15.](image2)
The battery is charging during the night in the third test. It is unknown if it charges due to the batteries inner functions or to the electrical tariffs because the battery starts on a low SoC in the beginning. During the rest of the time-intervals is the SoC for the battery almost constant, which means that it is not following the electrical tariff.

In the fourth test was costs for the shoulder-peaks and for the top-peaks that were way above the feed-in tariff cost used. This was done because the cost-edge for controlling the energy-flow had to be known. How the peak ratio was related to the power flow.

Figure 17. Electrical tariff for PPAMs energy storage with cost off-peak 0.25, shoulder-peak 3.0 and the top-peak 4.0 SEK. Test four.

The SoC during this test was almost the same as in test one.

Figure 18. State of Charge-diagram for PPAMs batteries for the electrical tariff in figure 17.
The battery has a SoC value around 50% in the beginning, very close to what it had in the first test. During 11:00 AM and 1:00 PM was the shoulder-peak cost set, which means that the battery should not charge if it follows the electrical tariff. The off-peak cost was set during 1:00 PM and 5:00 PM, which means that the battery should charge but instead it discharged. This is not allowed to happen, because the highest energy-peaks is during 8:00 PM - 10:00 PM.

After four tests was peak-costs that were closer to the feed-in tariff used again, because the battery did charge during the night when that ratio was used in test three.

In the fifth test was the time-control for charging the battery during 1:00 AM - 6:00 AM, 8:00 AM - 11: AM and 1:00 PM - 4:00 PM used. The power flow for this test was 6 kW.

Figure 19. Electrical tariff for PPAMs energy storage with cost off-peak 0.25, the top-peak 1.0, shoulder-peak 0.21 and 0.5 SEK. Test five.

The time-control for charging the battery did not use the power flow that it was set to. The power flow was determined by how the current overflow and on which SoC value the battery was on. That shows that the battery gladly not want to take energy from the three-phase grid.
The battery state is in the beginning above 60% in figure 20 and it is charging. This indicates that it is a good ratio for the peak-costs.
Figure 21. State of Charge-diagram for PPAMs batteries for the electrical tariff in figure 19.

A test of charging the battery when the battery was at a lower SoC in the beginning was made to see if it still worked and not following its inner functions. Which it did at 5.15 AM but not during the whole time-charging interval.

4.4. Modeling of the energy storage regulation for Time of Use

A way of doing an energy regulation can be to use different energy sources at different times. Chiang, Chang and Yen used four time periods in their energy regulation. Where the period one and two were between 22:00-06:00 and 06:00-08:00. The time period for three and four was between 08:00-17:00 and 17:00-22:00. During period one was there no sun up and therefore did they charge the battery and the household from the three-phase grid. At period two was there a little bit of solar production. In this case did they use the solar panel system and the three-phase grid to charge the batteries and the household. During the time at period three was the sun at the top of the sky. The solar production was then high, and the use of the three-phase grid was often not being needed. The energy that came from the solar panels went to the batteries, household and the rest of the energy went to the three-phase grid. During the fourth period did they use the solar panels if there was any radiation. The peak load occurred at this hour therefore did they prioritize the batteries to charge the household than over the grid. (Chiang, Chang and Yen, 1998).
Figure 22. Flow chart of the time-interval regulation.

Chiang, Chang and Yens method was used in this project but with more time periods. Ekoxen’s peak load came very often and sometimes randomly as was shown in figure 10 and that was why these other time-intervals was needed. These time periods were used in the spreadsheet tool for simulation, both the Time-of-Use and modbus estimation. A = 1 for charging, -1 for discharging the battery.

For the modeling of the energy storage regulation according to time intervals, some standard equations were needed to be known. The regulation was modeled in the spreadsheet tool and it had to reflect on how the system worked at Ekoxen.

The primary task was to solve the energy flow for the energy storage in the system. To do that, the energy from the three-phase grid, solar panels and the consumption for Ekoxen was needed to be considered.

If $P_{Solar,t} > P_{Load,t}$ the excess energy i.e what is left of $P_{Solar,t}$ after the consumption $(P_{Solar,t} - P_{Load,t})$ is used to charge the battery but only if $SoC(t) < SoC_{max}$. If the battery is fully charged, then the excess energy is sold to the grid. During peak time if $P_{Load,t} > P_{Solar,t}$ then the battery is used to feed the load (Nayak C. K. and Nayak M. R., 2017).

The equation below shows how much power that is transferred from and to the three-phase grid. In that equation is the power to the household ($P_{Load,t}$), the solar power ($P_{Solar,t}$) and the power flow ($P_{Bat,t}$) determined. The power flow is positive when the batteries are charging. (Teja and Yemula, 2016)

$$P_{Three-phase\ grid,t} = P_{Load,t} \pm P_{Bat,t} - P_{Solar,t} \quad (4.4)$$
Another energy source that needed to be calculated was the energy storage.

\[
E_{\text{Bat},t} = \sum_{0}^{t} (\eta^0 \ast \alpha_t \ast P_{\text{Bat},t}) \tag{4.5}
\]

Equation 4.5 calculates how much energy that have been stored in the battery. The AC/DC inverter- and the battery efficiency during charging and discharging \((\eta)\) needs to be known. The discharging or charging constant for the battery does also need to be known, which \(\alpha_t\) corresponds to \((\alpha = 1\) for charging, -1 for discharging). The power flow for the battery does also need to be estimated. (Teja and Yemula, 2016)

To make equation (4.4) and (4.5) to work, some criteria needs to be set. Here \(E^\text{max}_{\text{Bat}}\) corresponds to maximum accessible energy, not the total energy capacity of the energy storage system.

The main criteria for equation (4.5):

If \(E_{\text{Bat},t} = E^\text{min}_{\text{Bat}}\) then \(\alpha_t \geq 0\). \tag{4.6}

This criterion means that if the energy in the battery is at the minimum stored energy, charge the battery with a charging power bigger or equal to zero.

If \(E_{\text{Bat},t} = E^\text{max}_{\text{Bat}}\) then \(\alpha_t \leq 0\). \tag{4.7}

If the battery capacity is fully charged, the discharging power will either be below or above zero.

If \(E^\text{min}_{\text{Bat}} < E_{\text{Bat},t} < E^\text{max}_{\text{Bat}}\) then \(\alpha_t \neq 0\) \tag{4.8}

If \(\alpha_t \neq 0\) then \(P_{\text{Bat},t} = P_{\text{Solar},t} - P_{\text{Load},t}\) \tag{4.9}

The power flow, \(P_{\text{Bat},t}\) has some limitations and criterias

\[
P_{\text{Bat},t} = P^\text{max}_{\text{Bat}} \ast k, \quad 0 \leq k \leq 1 \tag{4.10}
\]

where \(k\) is the coefficient which is set in time-of-use. Of course, can \(P_{\text{Bat},t}\) not exceed its limitations

\[
P^\text{min}_{\text{Bat}} \leq P_{\text{Bat},t} \leq P^\text{max}_{\text{Bat}} \tag{4.11}
\]

Behavior for charging, \(\alpha_t > 0\):

If \(P_{\text{Solar},t} - P_{\text{Load},t} < P^\text{max}_{\text{Bat}} \ast k\) then the rest of the needed energy is drawn from \(P_{\text{Three-phase grid},t}\).

If \(P_{\text{Solar},t} - P_{\text{Load},t} > P^\text{max}_{\text{Bat}} \ast k\) then the rest of \(P_{\text{Solar},t}\) is feed in to the \(P_{\text{Three-phase grid},t}\).

Behavior for discharging, \(\alpha_t < 0\):

\[
E_{\text{Bat},t} = \sum_{0}^{t} (\eta^0 \ast \alpha_t \ast P_{\text{Bat},t}) 
\]
If \( P_{\text{Solar},t} - P_{\text{Load},t} < -P_{\text{Bat}}^{\text{max}} \times k \) then the rest of the needed energy is drawn from \( P_{\text{Three-phase grid},t} \).

If \( P_{\text{Solar},t} - P_{\text{Load},t} > P_{\text{Bat}}^{\text{max}} \times k \) then there is no need to discharge, instead, if needed, will the batteries be charged.

There are two input parameters for each time period. In figure 22 there are just approximate values of the power flow coefficient. Depending on how the consumption profile, these discharge/charge and power flow coefficients are set differently.

<table>
<thead>
<tr>
<th>Time</th>
<th>Discharge/Charge</th>
<th>Power flow coefficient [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>22:00 - 06:00</td>
<td>( \alpha )</td>
<td>( k )</td>
</tr>
<tr>
<td>06:00 - 9:00</td>
<td>( \alpha )</td>
<td>( k )</td>
</tr>
<tr>
<td>9:00 - 10:00</td>
<td>( \alpha )</td>
<td>( k )</td>
</tr>
<tr>
<td>10:00 - 12:00</td>
<td>( \alpha )</td>
<td>( k )</td>
</tr>
<tr>
<td>12:00 - 15:00</td>
<td>( \alpha )</td>
<td>( k )</td>
</tr>
<tr>
<td>15:00 - 16:00</td>
<td>( \alpha )</td>
<td>( k )</td>
</tr>
<tr>
<td>16:00 - 22:00</td>
<td>( \alpha )</td>
<td>( k )</td>
</tr>
</tbody>
</table>

Table 2. Discharge / charge and power flow coefficients.

The calculations for the battery that has been used are mostly for the discharge and the charge calculations. The calculations do also follow the accessible limits for the battery. The charge/discharge power will be the most important parameter to decide to make the energy regulating as good as possible.
Figure 23. The energy storage procedure. 

The energy storage changes its accessible energy between the winter and summer months. It does this because the inverter that are connected to the battery are changing it according to the “self consumption” limits.

The accessible energy according to the self consumption for the battery was calculated as:

\[ E_{\text{Bat},t} = E_{\text{Bat},t} + E_{\text{Bat-tot}} \times (0.2 / 182.5) \]  
(4.12)

where \( E_{\text{Bat},t} \) increases from 21st of December - 21st of June

\[ E_{\text{Bat},t} = E_{\text{Bat},t} - E_{\text{Bat-tot}} \times (0.2 / 182.5) \]  
(4.13)

and decrease from 21 of June - 21 of December.

\( E_{\text{Bat-tot}} \) stands for the total battery capacity and \((0.2 / 182.5)\) is the increase/ decrease coefficient. The accessible battery storage is 20% larger on 21st of June than 21st of December.

The calculation needed a start value, because the profiles starts at the 1st of January. The start value was calculated as:

\[ E_{\text{Bat},t} = E_{\text{Bat-tot}} \times 0.35 + 10 \times E_{\text{Bat-tot}} \times (0.25 / 182.5) \]  
(4.14)

where the lower state of charge limit is at 65%, which occurs in December 21st.

4.4.1. Modeling for Modbus

The Modbus communication system is a PLC based system which makes it more flexible when program it. Time-of-use program controls when to discharge and charge the battery and with what power flow. Other parameters can be considered in modbus, such as the mean consumption over the day and the maximum consumption in the month so far. These parameters were considered when an extra feature was added to the simulation tool. This feature can be useful for further work if PPAM decides to implement an algorithm in modbus.

This extra feature is an addon for the time of use modelling. With this addon the simulation tool works as before except the program is checking the consumption history and takes actions whether the current consumption is higher or lower than that.

The mean power consumption over the day \( P_{\text{Grid,mean}} \) is calculated for each day. To be clear, \( P_{\text{Grid,mean}} \) is the average power that is bought from the power grid.

\[ P_{\text{Three-phase grid,Day}} = P_{\text{Three-phase Grid,Day}} + P_{\text{Three-phase grid,t}} \]  
(4.4.1)

\[ P_{\text{Three-phase grid,mean}} = P_{\text{Three-phase Grid,Day}} / 24 \]  
(4.4.2)
$P_{\text{three-phase grid, Day}}$ is calculated for each hour and in the end of the day are calculated by dividing $P_{\text{three-phase grid, Day}}$ by the hours of the day. $P_{\text{three-phase grid, mean}}$ is then being looked at to determine a more efficient power flow from and to the battery.

The power flow is determined by looking at the $P_{\text{three-phase grid, mean}}$ the day before. $P_{\text{three-phase grid, mean}}$ is much higher during the winter, it increases during the winter and decreases during the summer. By looking at it every day there is only minor differences in $P_{\text{three-phase grid, mean}}$. The power flow is only altered when criteria based on how large $P_{\text{three-phase grid, mean}}$ are fulfilled, otherwise the standard way of determining the power flow is used.

Criteria for when the power flow is altered

$$\text{If } P_{\text{three-phase grid, t}} > P_{\text{three-phase grid, mean}} + P_{\text{Bat, max}} \text{ AND } E_{\text{Bat, t}} > \left( \frac{E_{\text{Bat, max}}^{\text{max}}}{2} \right)$$

(4.4.3)

Then

$$P_{\text{Bat, t}} = P_{\text{three-phase grid, t}} - P_{\text{three-phase grid, mean}} + P_{\text{Bat, max}}$$

(4.4.4)

This check makes sure that there are no top-peaks outside the predicted intervals of the top peaks and if there is more than 50% of usable energy in the batteries then the batteries are discharging.

**Consumption during 24h in January**

![Graph showing consumption during 24h in January](image)

*Figure 24. Description of peak shaving algorithm.*
The blue line represents \( P_{\text{Three-phase grid, mean}} + P_{\text{Bat, max}} \) and if \( P_{\text{Three-phase grid, t}} \) is larger than \( P_{\text{Three-phase grid, mean}} + P_{\text{Bat, max}} \) then if possible the battery will cut the peak. The yellow part represents the energy that is needed to cut the peak. The batteries discharge power can of course not exceed \( P_{\text{Bat, max}} \). A limit of 50% of usable energy in the batteries are set due to save energy to the night time, i.e. save energy to when the most consumption takes place during the day.

The maximum power consumption for the month so far \( P_{\text{three-phase grid, max}} \) is calculated for each day. \( P_{\text{Three-phase grid, max}} \) is the maximum power that is bought from the three-phase grid so far for a month.

\[
P_{\text{Three-phase grid, max}} \text{ is checked every hour and if}
\]

\[
P_{\text{three-phase grid, t}} > P_{\text{three-phase grid, max}} \quad \text{then} \\
P_{\text{three-phase grid, max}} = P_{\text{three-phase grid, t}} \quad (4.4.5)
\]

At the start of every month \( P_{\text{Three-phase grid, max}} \) is set to \( P_{\text{Three-phase grid, max}} * 2/3 \) or else the algorithm would interfere in the wrong way. If \( P_{\text{Three-phase grid, max}} \) would be set to 0 then the at the start of every month the algorithm would try to increase the power flow even if not necessary due to a low \( P_{\text{Three-phase grid, max}} \).

Criteria for when the power flow is altered:

If \((P_{\text{Three-phase grid, t}} + P_{\text{Bat, t}} > P_{\text{Three-phase grid, max}}) \) AND \( E_{\text{Bat, t}} > (E_{\text{Bat, t}}^{\text{max}} - P_{\text{Bat, t}}) \) (4.4.7)

Then \( \alpha_t = -1 \) and \( k = 0.5 \) (4.4.8)

This check if the energy storage is almost 100% and if the consumption is high. In some cases, the system would have wanted to charge the battery storage and possible make \( P_{\text{three-phase grid, t}} \) even bigger, but cause of a lot of energy in the battery storage it is smart to discharge with half the power flow. This can only occur if (4.2.9) did not occur.

Then a third check is done

If \( P_{\text{three-phase grid, t}} + P_{\text{Bat, t}} > P_{\text{three-phase grid, max}} \) AND \( \alpha_t = 1 \) (4.4.9)

Then \( \alpha_t = 1 \) and \( k = 0.1 \) (4.4.10)

This causes the system not to discharge with higher power flow than 10% of max power flow when the consumption is high.
Figure 25. Flow chart for the modbus modeling.
5. Results
Results from the simulations of Time-of-Use and for the modbus feature are displayed here.

5.1. Results from Time-of-Use in spreadsheet simulations
Results of the Time-of-Use simulations will be displayed. The tests uses different power flow and sometimes different discharging and charging period. Maximum power flow in these tests is 14 kW. Two different tests are presentent, one for the months with the highest solar irradiation, June - August and one test for the rest of the year. It turned out to be favourable to set different coefficients for the summer months due to higher solar irradiation and lower consumption. A typical day and month are both shown in both of the test in order to show that the winter coefficients are not optimal for the summer and vice versa. In the results below, June - August are called the summer months and the rest of the months are called the winter months.

5.1.1. Optimal coefficients for winter months
In the first test was the optimization for the energy flow during the winter months done. The coefficients were set after an iterative process to find the best results.

<table>
<thead>
<tr>
<th>Time:</th>
<th>Discharge/Charge $\alpha_t$</th>
<th>Power flow coefficient [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>22:00 - 06:00</td>
<td>1</td>
<td>70</td>
</tr>
<tr>
<td>06:00 - 9:00</td>
<td>-1</td>
<td>0</td>
</tr>
<tr>
<td>9:00 - 10:00</td>
<td>1</td>
<td>45</td>
</tr>
<tr>
<td>10:00 - 12:00</td>
<td>-1</td>
<td>0</td>
</tr>
<tr>
<td>12:00 - 15:00</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>15:00 - 16:00</td>
<td>-1</td>
<td>75</td>
</tr>
<tr>
<td>16:00 - 22:00</td>
<td>-1</td>
<td>100</td>
</tr>
</tbody>
</table>

*Table 3. Discharge / charge time and power flow coefficient for winter-time.*
Figure 26. Energy flow during one day in July for the winter test.

In figure 26 can the energy flow for the solar panel system be seen for a day in July. The yellow curve corresponds to the accessible battery capacity, which are between the state of charge limits. The green curve corresponds to the solar power, the blue curve corresponds to the energy that flows to the three-phase net, the red curve corresponds to the power consumption and the black curve corresponds to the energy that comes from the three-phase net. For the yellow curve can it be seen that the battery is fully charged from 8 AM to 17 PM, that is because that it is solar power during this day in July. This can harm the batteries lifetime and it is not necessary because the top-peak is not that high.
In figure 27 can it be seen that the battery is fully loaded at the start of the evening. Due to the changes of the accessible energy, the storage is fully loaded for a relative long time during the day. It can also be seen that the storage is empty at 9 PM. On the other hand, this only occur during the shortest days of the year.

Figure 28. Accumulated losses from charging and discharging the simulated battery during 24 hours in July and January during the winter test.
The accumulated losses between a day in July and January in the winter test is almost the same which can be seen in figure 28. It can be seen that the losses are a bit lower in January during 6 AM to 10 AM. The simple reason to that is that the battery is not charging or discharging as much as it does in July.

![Power peaks from three phase grid for each day in July](image)

*Figure 29. Power peaks from the three-phase net for each day in July for the winter test.*

In figure 29 can the power peaks for the system be seen. The red curve corresponds to the unshaved power peaks from the three-phase net. The green curve corresponds to the power peaks from the three-phase net when it is shaved by the solar energy and the blue curve corresponds to the power peaks from the three-phase net when it is shaved by the discharged energy from the battery and with the solar energy. In this case does the energy regulation of the battery just increase the power peaks for almost all days, if it compares with the green curve. That is not what the regulation are supposed to do.
Figure 30. Power peaks from the three-phase net for each day in January for the winter test.

Figure 30 shows how much the regulation was able to lower the peaks for January. The solar panels only had an impact at day 7.

Figure 31. How the battery behaves during each day in July for the winter test.
In Figure 31, the orange curve represents the state of charge for the battery in July. The black dotted curve is the limit in which the state of charge cannot go below. With the winter coefficients, the graph shows that the battery is full during a long period of the day with some exceptions.

![Battery behavior during January](image)

*Figure 32. How the battery behaves during each day in January for the winter test.*

During January with the winter coefficients it can be seen that the system uses the total accessible battery capacity each day, which can be seen in figure 32.
Figure 33. Power peaks from the three-phase grid for each month for the winter test.

Figure 33 is structured in the same way as figure 30 and figure 29, but here is the x-axis in months. The figure shows that the blue curve (peak reduced with the energy from the battery and the solar energy) is lower than the rest of the curves, but it is not exact the same disparity for all of the months.

<table>
<thead>
<tr>
<th>Month</th>
<th>Peak reduced kW</th>
<th>Saved cost SEK</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jan</td>
<td>14,0</td>
<td>1666,0</td>
</tr>
<tr>
<td>Feb</td>
<td>14,0</td>
<td>1666,0</td>
</tr>
<tr>
<td>Mar</td>
<td>14,0</td>
<td>1666,0</td>
</tr>
<tr>
<td>Apr</td>
<td>14,0</td>
<td>1666,0</td>
</tr>
<tr>
<td>May</td>
<td>14,0</td>
<td>1666,0</td>
</tr>
<tr>
<td>Jun</td>
<td>9,2</td>
<td>1096,7</td>
</tr>
<tr>
<td>Jul</td>
<td>13,2</td>
<td>1572,7</td>
</tr>
<tr>
<td>Aug</td>
<td>8,2</td>
<td>972,4</td>
</tr>
<tr>
<td>Sep</td>
<td>14,0</td>
<td>1666,0</td>
</tr>
<tr>
<td>Oct</td>
<td>14,0</td>
<td>1666,0</td>
</tr>
<tr>
<td>Nov</td>
<td>14,0</td>
<td>1666,0</td>
</tr>
<tr>
<td>Dec</td>
<td>14,0</td>
<td>1666,0</td>
</tr>
<tr>
<td>Total</td>
<td>156,6</td>
<td>18635,7</td>
</tr>
<tr>
<td>Average</td>
<td>13,1</td>
<td>1553,0</td>
</tr>
</tbody>
</table>

Table 4. Peak reduction and corresponding cost during the winter test.
A better check of the difference between the curves in figure 33 can be seen in table 4, in the column “Peak reduced”. The top-peaks are shaved with 14 kW for all winter months, but not for June, July, and August. The “Saved cost” column corresponds to how much the reduced energy costs.

### 5.1.2. Optimal coefficients for the summer months

Second test shows the result of the best coefficients for the summer months.

<table>
<thead>
<tr>
<th>Time:</th>
<th>Discharge/Charge $\alpha_t$</th>
<th>Power flow coefficient [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>22:00 - 06:00</td>
<td>1</td>
<td>57</td>
</tr>
<tr>
<td>06:00 - 9:00</td>
<td>$-1$</td>
<td>15</td>
</tr>
<tr>
<td>9:00 - 10:00</td>
<td>1</td>
<td>20</td>
</tr>
<tr>
<td>10:00 - 12:00</td>
<td>$-1$</td>
<td>0</td>
</tr>
<tr>
<td>12:00 - 15:00</td>
<td>$-1$</td>
<td>20</td>
</tr>
<tr>
<td>15:00 - 16:00</td>
<td>$-1$</td>
<td>15</td>
</tr>
<tr>
<td>16:00 - 22:00</td>
<td>$-1$</td>
<td>100</td>
</tr>
</tbody>
</table>

**Table 5. Discharge / charge time and power flow coefficients for the summer test.**

![Figure 34](image-url)  

Figure 34. Energy flow during one day in July for the summer test.

Figure 34 represents the energy flow in the solar panel system during a day in July for the summer test. The difference between figure 34 and figure 26 is the amount of stored energy in the battery. In the making of this test was the amount of solar energy in mind, which can be seen on the yellow curve. The battery did not need to be fully charged at 8 AM because of the solar energy.
With the summer coefficients the accessible battery capacity does not reach over 75%, this results in an empty storage at 8 PM. As seen in figure 35 versus figure 27, the winter coefficients are much more suitable for January.

Figure 35. Energy flow during one day in January for the summer test.

Figure 36. Accumulated losses from charging and discharging the simulated battery during 24 hours in July and January during the summer test.
The accumulated losses in figure 36 differs from the losses in figure 28, that is because the amount of discharging and charging in the winter months is not considered in this case.

**Figure 37. Power peaks from the three-phase grid during each day in July for the summer test.**

In figure 37 it can be seen that the power peaks from the three-phase grid with solar power and battery is less shifting from day to day than power peaks from the other two scenarios.
Figure 38. Power peaks from the three-phase grid during each day in January for the summer test.
With the summer coefficients for January the power peaks cannot be reduced. This is due to low energy in the battery.

![Battery behavior during July](image)

Figure 39. How the battery behaves during each day in July for the summer test.

Figure 39 represents the batteries behavior during July. The battery is not fully charged during the days 1 and 20 to 25. Which can be bad for the shaving of the top-peaks.
Figure 40. How the battery behaves during each day in January for the summer test.

Figure 40 shows that the battery is not fully charged during a day.

Figure 41. Power peaks from the three-phase grid during each month for the summer test.
In figure 41 can it be seen that the solar power and the discharged energy from battery is best on shaving the top-peaks, but the difference between the blue curve and the green curve is still not exact for each month. It is not shaved with exact 14 kW.

<table>
<thead>
<tr>
<th>Month</th>
<th>Peak reduced kW</th>
<th>Saved cost SEK</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jan</td>
<td>14,0</td>
<td>1666,0</td>
</tr>
<tr>
<td>Feb</td>
<td>14,0</td>
<td>1666,0</td>
</tr>
<tr>
<td>Mar</td>
<td>8,6</td>
<td>1025,2</td>
</tr>
<tr>
<td>Apr</td>
<td>9,9</td>
<td>1175,2</td>
</tr>
<tr>
<td>May</td>
<td>5,6</td>
<td>668,20</td>
</tr>
<tr>
<td>Jun</td>
<td>11,0</td>
<td>1312,9</td>
</tr>
<tr>
<td>Jul</td>
<td>14,0</td>
<td>1666,0</td>
</tr>
<tr>
<td>Aug</td>
<td>11,7</td>
<td>1388,2</td>
</tr>
<tr>
<td>Sep</td>
<td>11,6</td>
<td>1382,2</td>
</tr>
<tr>
<td>Oct</td>
<td>14,0</td>
<td>1666,0</td>
</tr>
<tr>
<td>Nov</td>
<td>8,1</td>
<td>963,9</td>
</tr>
<tr>
<td>Dec</td>
<td>14,0</td>
<td>1666,0</td>
</tr>
<tr>
<td>Total</td>
<td>139,0</td>
<td>16245,0</td>
</tr>
<tr>
<td>Average</td>
<td>11,6</td>
<td>1353,8</td>
</tr>
</tbody>
</table>

*Table 6. Peak reduction and corresponding cost during the summer test.*

Table 6 shows how much the top-peaks was shaved for each month in the column “Peak reduced”. The top-peaks are only reduced with 14 kW in January, February, July, October and in December, which was not the goal for the summer test. The summer test had the goal to shave with 14 kW in June, July and August.
5.2. Results with added modbus feature to the spreadsheet tool

Results will be shown when 14 kW was used as maximum power flow, which was the main goal to manage. Later will results for when exceeding the maximum power flow be shown, but with the same power flow coefficients that were used for 14 kW.

5.2.1. Energy regulation results when using 14 kW as power flow

Charge during the night and day, discharge during the evening and let the peak shaving algorithm take care of the irregular power peaks during the day.

<table>
<thead>
<tr>
<th>Time:</th>
<th>Discharge/Charge $a_i$</th>
<th>Power flow coefficient [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>22:00 - 06:00</td>
<td>1</td>
<td>50</td>
</tr>
<tr>
<td>06:00 - 9:00</td>
<td>1</td>
<td>60</td>
</tr>
<tr>
<td>9:00 - 10:00</td>
<td>1</td>
<td>60</td>
</tr>
<tr>
<td>10:00 - 12:00</td>
<td>1</td>
<td>60</td>
</tr>
<tr>
<td>12:00 - 15:00</td>
<td>1</td>
<td>60</td>
</tr>
<tr>
<td>15:00 - 16:00</td>
<td>1</td>
<td>60</td>
</tr>
<tr>
<td>16:00 - 22:00</td>
<td>−1</td>
<td>100</td>
</tr>
</tbody>
</table>

Table 7. Discharge / charge time and power flow coefficients for the modbus test.

Figure 42. Energy flow during one day in July when using 14 kW as max power flow.
Figure 43. Energy flow during one day in January when using 14 kW as max power flow.

Figure 42 and 43 shows that the battery behavior is acceptable in both summer and winter.

Figure 44. Accumulated losses from charging and discharging the simulated battery during 24 hours in July and January when using 14 kW as max power flow.

Figure 44 shows that the losses is approximately the same as for the time of use tests.
Figure 45. Power peaks during each day in July when using 14 kW as max power flow.

Figure 45 shows that the top-peaks are reduced better with the solar energy (green curve) during day 15 and day 24 in July, but the goal was to only shave with 14 kW. Which is what the blue curve shows.

Figure 46. Power peaks during each day in January when using 14 kW as max power flow.

In figure 46 is the battery regulation with the solar energy better on shaving the top-peaks. That is mostly because of the low solar energy during this month.
Figure 47. Battery behavior during July when using 14 kW as max power flow.

Figure 48. Battery behavior during January when using 14 kW as max power flow.
With the modbus feature the battery behavior for January and July is better in both cases. The battery is charged to the maximum and the state of charge is not at 100% for very long.

![Power peaks from three phase grid for each month](image)

**Figure 49. Power peaks from the three-phase grid during each month when using 14 kW as max power flow.**

<table>
<thead>
<tr>
<th>Month</th>
<th>Peak reduced kW</th>
<th>Saved cost SEK</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jan</td>
<td>14,0</td>
<td>1666,0</td>
</tr>
<tr>
<td>Feb</td>
<td>14,0</td>
<td>1666,0</td>
</tr>
<tr>
<td>Mar</td>
<td>14,0</td>
<td>1666,0</td>
</tr>
<tr>
<td>Apr</td>
<td>14,0</td>
<td>1666,0</td>
</tr>
<tr>
<td>May</td>
<td>14,0</td>
<td>1666,0</td>
</tr>
<tr>
<td>Jun</td>
<td>14,0</td>
<td>1666,0</td>
</tr>
<tr>
<td>Jul</td>
<td>14,0</td>
<td>1666,0</td>
</tr>
<tr>
<td>Aug</td>
<td>14,0</td>
<td>1666,0</td>
</tr>
<tr>
<td>Sep</td>
<td>14,0</td>
<td>1666,0</td>
</tr>
<tr>
<td>Oct</td>
<td>14,0</td>
<td>1666,0</td>
</tr>
<tr>
<td>Nov</td>
<td>14,0</td>
<td>1666,0</td>
</tr>
<tr>
<td>Dec</td>
<td>14,0</td>
<td>1666,0</td>
</tr>
<tr>
<td>Total</td>
<td>168,0</td>
<td>19992,0</td>
</tr>
<tr>
<td>Average</td>
<td>14,0</td>
<td>1666,0</td>
</tr>
</tbody>
</table>

**Table 8. Peak reduction and corresponding cost when using 14 kW as max power flow.**

The top-peaks are exact reduced with 14 kW during this test, which can be seen in figure 49 and in table 8.
Figure 50. Accumulated cost for Ekoxen when using 14 kW as max power flow.

Figure 50 represents the cost of the energy flow. The green curve corresponds to cost of the energy flow when solar power is used. The red curve corresponds to the cost of the energy flow when the battery and the solar power is unused. The blue curve corresponds to the cost of the energy flow when the solar power and the battery is used. The figure shows that it is better to used battery and solar power to lower the cost of the energy flow.
5.2.2. Energy regulation results when using different power flows

Tests was made to see if the peaks could be reduced with the maximum power flow if the maximum power flow was increased. Two tests were made one with 16 kW and one with 18 kW as power flow.

![Power peaks from three phase grid for each month](image)

*Figure 51. Power peaks from the three-phase grid during each month when using 16 kW as max power flow.*

<table>
<thead>
<tr>
<th>Month</th>
<th>Peak reduced kW</th>
<th>Saved cost SEK</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jan</td>
<td>16.0</td>
<td>1904.0</td>
</tr>
<tr>
<td>Feb</td>
<td>16.0</td>
<td>1904.0</td>
</tr>
<tr>
<td>Mar</td>
<td>16.0</td>
<td>1904.0</td>
</tr>
<tr>
<td>Apr</td>
<td>16.0</td>
<td>1904.0</td>
</tr>
<tr>
<td>May</td>
<td>16.0</td>
<td>1904.0</td>
</tr>
<tr>
<td>Jun</td>
<td>16.0</td>
<td>1904.0</td>
</tr>
<tr>
<td>Jul</td>
<td>16.0</td>
<td>1904.0</td>
</tr>
<tr>
<td>Aug</td>
<td>16.0</td>
<td>1904.0</td>
</tr>
<tr>
<td>Sep</td>
<td>16.0</td>
<td>1904.0</td>
</tr>
<tr>
<td>Oct</td>
<td>16.0</td>
<td>1904.0</td>
</tr>
<tr>
<td>Nov</td>
<td>16.0</td>
<td>1904.0</td>
</tr>
<tr>
<td>Dec</td>
<td>16.0</td>
<td>1904.0</td>
</tr>
<tr>
<td>Total</td>
<td>192.0</td>
<td>22848.0</td>
</tr>
<tr>
<td>Average</td>
<td>16.0</td>
<td>1904.0</td>
</tr>
</tbody>
</table>

*Table 9. Peak reduction and corresponding cost when using 16 kW as max power flow.*
Table 9 and figure 51 shows that the modbus feature will work for 16 kW as max power flow as well.

![Power peaks from three phase grid for each month](image)

**Figure 52.** Power peaks from the three-phase grid during each month when using 18 kW as max power flow.

<table>
<thead>
<tr>
<th>Month</th>
<th>Peak reduced kW</th>
<th>Saved cost SEK</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jan</td>
<td>17,8</td>
<td>2115,6</td>
</tr>
<tr>
<td>Feb</td>
<td>18,0</td>
<td>2142,0</td>
</tr>
<tr>
<td>Mar</td>
<td>18,0</td>
<td>2142,0</td>
</tr>
<tr>
<td>Apr</td>
<td>18,0</td>
<td>2142,0</td>
</tr>
<tr>
<td>May</td>
<td>18,0</td>
<td>2142,0</td>
</tr>
<tr>
<td>Jun</td>
<td>17,0</td>
<td>2024,7</td>
</tr>
<tr>
<td>Jul</td>
<td>18,0</td>
<td>2142,0</td>
</tr>
<tr>
<td>Aug</td>
<td>12,7</td>
<td>1507,0</td>
</tr>
<tr>
<td>Sep</td>
<td>17,7</td>
<td>2111,4</td>
</tr>
<tr>
<td>Oct</td>
<td>18,0</td>
<td>2142,0</td>
</tr>
<tr>
<td>Nov</td>
<td>18,0</td>
<td>2138,0</td>
</tr>
<tr>
<td>Dec</td>
<td>18,0</td>
<td>2142,0</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>209,2</strong></td>
<td><strong>24890,7</strong></td>
</tr>
<tr>
<td><strong>Average</strong></td>
<td><strong>17,4</strong></td>
<td><strong>2074,2</strong></td>
</tr>
</tbody>
</table>

**Table 10.** Peak reduction and corresponding cost when using 18 kW as max power flow.

Table 10 and figure 52 shows that the peak shaving will not be that effective with 18 kW as maximum power flow.
5.3. Energy flow and cost results for the solar panel system

The tables in 5.3 shows the energy flow and the corresponding cost for the system. Remember that the energy flow in these tables are controlled with the energy regulation. Six tables will be shown for the system, three tables for the system with only solar power and three tables for the system with solar power and battery. In the first table for each scenario the energy balance can be seen, the second table shows the saved cost and the third table shows the total cost for Ekoxen.

5.3.1. Results for solar panel system without battery

<table>
<thead>
<tr>
<th>Month</th>
<th>Consumption kWh</th>
<th>Max kW</th>
<th>Solar production kWh</th>
<th>Max kW</th>
<th>Overflow kWh</th>
<th>Max kW</th>
<th>Out from grid kWh</th>
<th>Max kW</th>
<th>Saved Energy kWh</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jan</td>
<td>21243,0</td>
<td>68,0</td>
<td>1253,7</td>
<td>41,1</td>
<td>10,0</td>
<td>8,1</td>
<td>19999,3</td>
<td>68,0</td>
<td>1243,70</td>
</tr>
<tr>
<td>Feb</td>
<td>18922,0</td>
<td>71,0</td>
<td>3042,8</td>
<td>47,4</td>
<td>105,8</td>
<td>19,2</td>
<td>15985,01</td>
<td>71,0</td>
<td>2936,99</td>
</tr>
<tr>
<td>Mar</td>
<td>19507,0</td>
<td>61,0</td>
<td>7138,5</td>
<td>59,1</td>
<td>1171,1</td>
<td>36,1</td>
<td>13539,54</td>
<td>61,0</td>
<td>5967,46</td>
</tr>
<tr>
<td>Apr</td>
<td>19937,0</td>
<td>59,0</td>
<td>9941,4</td>
<td>62,5</td>
<td>2346,4</td>
<td>40,5</td>
<td>12342,00</td>
<td>58,0</td>
<td>7595,00</td>
</tr>
<tr>
<td>May</td>
<td>16569,0</td>
<td>50,0</td>
<td>12366,3</td>
<td>66,5</td>
<td>4513,2</td>
<td>49,5</td>
<td>8715,90</td>
<td>50,0</td>
<td>7853,10</td>
</tr>
<tr>
<td>Jun</td>
<td>13449,0</td>
<td>42,0</td>
<td>12526,6</td>
<td>61,6</td>
<td>5288,7</td>
<td>46,0</td>
<td>6211,04</td>
<td>40,0</td>
<td>7237,96</td>
</tr>
<tr>
<td>Jul</td>
<td>12999,0</td>
<td>43,0</td>
<td>11332,3</td>
<td>60,3</td>
<td>4248,2</td>
<td>44,3</td>
<td>5914,86</td>
<td>39,0</td>
<td>7084,14</td>
</tr>
<tr>
<td>Aug</td>
<td>13626,0</td>
<td>47,0</td>
<td>9855,5</td>
<td>61,6</td>
<td>3916,0</td>
<td>45,6</td>
<td>7686,49</td>
<td>42,37</td>
<td>5939,51</td>
</tr>
<tr>
<td>Sep</td>
<td>16877,0</td>
<td>56,0</td>
<td>7689,8</td>
<td>57,5</td>
<td>2083,8</td>
<td>38,4</td>
<td>11271,00</td>
<td>56,0</td>
<td>5606,00</td>
</tr>
<tr>
<td>Oct</td>
<td>21350,0</td>
<td>67,0</td>
<td>4319,4</td>
<td>47,7</td>
<td>389,3</td>
<td>19,5</td>
<td>17419,86</td>
<td>67,0</td>
<td>3930,14</td>
</tr>
<tr>
<td>Nov</td>
<td>21604,0</td>
<td>66,0</td>
<td>1967,3</td>
<td>46,6</td>
<td>116,0</td>
<td>18,6</td>
<td>19752,70</td>
<td>66,0</td>
<td>1851,30</td>
</tr>
<tr>
<td>Dec</td>
<td>23284,0</td>
<td>72,0</td>
<td>1063,5</td>
<td>41,3</td>
<td>18,7</td>
<td>8,3</td>
<td>22239,25</td>
<td>72,0</td>
<td>1044,75</td>
</tr>
<tr>
<td>Sum</td>
<td>219367,0</td>
<td>82497,2</td>
<td>24207,2</td>
<td>161077,0</td>
<td>58290,05</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

| Per month: | | | | | | | | |
|------------|--------|--------|--------|--------|--------|--------|--------|--------|--------|
| Average    | 18280,6| 6874,8 | 2017,3 | 13423,1| 4857,50|
| Min        | 12999,0| 1063,5 | 10,0   | 5914,9 | 1044,75|
| Max        | 23284,0| 12526,6| 5288,7 | 22239,3| 7853,10|

Table 11. Energy results without battery.

The total energy flow for each source can be seen in table 11. The values come from the calculations/simulations that was done in the spreadsheet tool. In this case was the battery not in the calculation. The interesting part here is to compare the max consumption with the max energy that comes from the three-phase grid when the solar power has been used. The difference between those two are almost nothing. The total saved energy is this case is 58290 kW.
<table>
<thead>
<tr>
<th>Month</th>
<th>Transmission cost (Energy supplier)</th>
<th>Transmission cost (Grid owner)</th>
<th>Max. Power cost</th>
<th>Energy Tax</th>
<th>Tot cost incl VAT</th>
<th>Sold Energy</th>
<th>Tot SEK</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jan</td>
<td>932.8 SEK</td>
<td>100.0 SEK</td>
<td>0</td>
<td>514.6 SEK</td>
<td>1547.3 SEK</td>
<td>224.2 SEK</td>
<td>1771.5 SEK</td>
</tr>
<tr>
<td>Feb</td>
<td>2202.7 SEK</td>
<td>236.1 SEK</td>
<td>0</td>
<td>1215.2 SEK</td>
<td>3654.0 SEK</td>
<td>633.6 SEK</td>
<td>4287.6 SEK</td>
</tr>
<tr>
<td>Mar</td>
<td>4440.6 SEK</td>
<td>479.6 SEK</td>
<td>0</td>
<td>2469.0 SEK</td>
<td>7389.3 SEK</td>
<td>2501.7 SEK</td>
<td>9891.0 SEK</td>
</tr>
<tr>
<td>Apr</td>
<td>1708.9 SEK</td>
<td>610.4 SEK</td>
<td>119</td>
<td>3142.4 SEK</td>
<td>5580.8 SEK</td>
<td>4271.1 SEK</td>
<td>9851.8 SEK</td>
</tr>
<tr>
<td>May</td>
<td>1766.9 SEK</td>
<td>631.2 SEK</td>
<td>0</td>
<td>3249.2 SEK</td>
<td>5647.4 SEK</td>
<td>7066.8 SEK</td>
<td>12714.2 SEK</td>
</tr>
<tr>
<td>Jun</td>
<td>1628.5 SEK</td>
<td>581.8 SEK</td>
<td>238</td>
<td>2994.7 SEK</td>
<td>5443.0 SEK</td>
<td>7947.1 SEK</td>
<td>13390.1 SEK</td>
</tr>
<tr>
<td>Jul</td>
<td>1593.9 SEK</td>
<td>569.4 SEK</td>
<td>476</td>
<td>2931.1 SEK</td>
<td>5570.4 SEK</td>
<td>6599.5 SEK</td>
<td>12169.9 SEK</td>
</tr>
<tr>
<td>Aug</td>
<td>1336.4 SEK</td>
<td>477.4 SEK</td>
<td>551</td>
<td>2457.5 SEK</td>
<td>4822.0 SEK</td>
<td>5983.0 SEK</td>
<td>10805.1 SEK</td>
</tr>
<tr>
<td>Sep</td>
<td>1261.3 SEK</td>
<td>450.6 SEK</td>
<td>0</td>
<td>2319.5 SEK</td>
<td>4031.4 SEK</td>
<td>3599.5 SEK</td>
<td>7630.9 SEK</td>
</tr>
<tr>
<td>Oct</td>
<td>884.3 SEK</td>
<td>315.9 SEK</td>
<td>0</td>
<td>1626.1 SEK</td>
<td>2826.3 SEK</td>
<td>1162.5 SEK</td>
<td>3988.7 SEK</td>
</tr>
<tr>
<td>Nov</td>
<td>1388.5 SEK</td>
<td>148.8 SEK</td>
<td>0</td>
<td>766.0 SEK</td>
<td>2303.3 SEK</td>
<td>462.1 SEK</td>
<td>2765.3 SEK</td>
</tr>
<tr>
<td>Dec</td>
<td>783.6 SEK</td>
<td>84.0 SEK</td>
<td>0</td>
<td>432.3 SEK</td>
<td>1299.8 SEK</td>
<td>201.4 SEK</td>
<td>1501.2 SEK</td>
</tr>
<tr>
<td>Sum</td>
<td>19928.5 SEK</td>
<td>4685.1 SEK</td>
<td>1384</td>
<td>24117.5 SEK</td>
<td>50114.9 SEK</td>
<td>40652.4 SEK</td>
<td>90767.3 SEK</td>
</tr>
</tbody>
</table>

Table 12. Saved cost for the energy results without battery.

In table 12 can the total saved cost for the energy flow in the solar panel system be seen. The battery is still not in the equation. Ekoxen saves 90767,3 SEK when they use a solar panel system.
<table>
<thead>
<tr>
<th>Month</th>
<th>Subscription cost (Energy supplier)</th>
<th>Transmission cost (Grid owner)</th>
<th>Max. Power cost</th>
<th>Energy Tax</th>
<th>Tot cost incl VAT</th>
<th>Sold Energy</th>
<th>Total cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jan</td>
<td>600</td>
<td>12936,2</td>
<td>1607,4</td>
<td>8092</td>
<td>8274,7</td>
<td>31510,4</td>
<td>224,2</td>
</tr>
<tr>
<td>Feb</td>
<td>600</td>
<td>10166,0</td>
<td>1284,8</td>
<td>8449</td>
<td>6613,8</td>
<td>27113,5</td>
<td>633,6</td>
</tr>
<tr>
<td>Mar</td>
<td>600</td>
<td>8233,5</td>
<td>1088,2</td>
<td>7259</td>
<td>5602,0</td>
<td>22782,7</td>
<td>2501,7</td>
</tr>
<tr>
<td>Apr</td>
<td>600</td>
<td>2777,0</td>
<td>992,0</td>
<td>6902</td>
<td>5106,5</td>
<td>16377,4</td>
<td>4271,1</td>
</tr>
<tr>
<td>May</td>
<td>600</td>
<td>1961,1</td>
<td>700,5</td>
<td>5950</td>
<td>3606,2</td>
<td>12817,8</td>
<td>7066,8</td>
</tr>
<tr>
<td>Jun</td>
<td>600</td>
<td>1397,5</td>
<td>499,2</td>
<td>4760</td>
<td>2569,8</td>
<td>9826,5</td>
<td>7947,1</td>
</tr>
<tr>
<td>Jul</td>
<td>600</td>
<td>1330,8</td>
<td>475,4</td>
<td>4641</td>
<td>2447,3</td>
<td>9494,5</td>
<td>6599,5</td>
</tr>
<tr>
<td>Aug</td>
<td>600</td>
<td>1729,5</td>
<td>617,8</td>
<td>5042</td>
<td>3180,3</td>
<td>11169,8</td>
<td>5983,0</td>
</tr>
<tr>
<td>Sep</td>
<td>600</td>
<td>2536,0</td>
<td>905,9</td>
<td>6664</td>
<td>4663,4</td>
<td>15369,3</td>
<td>3599,5</td>
</tr>
<tr>
<td>Oct</td>
<td>600</td>
<td>3919,5</td>
<td>1400,1</td>
<td>7973</td>
<td>7207,5</td>
<td>21100,1</td>
<td>1162,5</td>
</tr>
<tr>
<td>Nov</td>
<td>600</td>
<td>12228,9</td>
<td>1587,6</td>
<td>7854</td>
<td>8172,7</td>
<td>30443,2</td>
<td>462,1</td>
</tr>
<tr>
<td>Dec</td>
<td>600</td>
<td>13978,8</td>
<td>1787,5</td>
<td>8568</td>
<td>9201,5</td>
<td>34135,8</td>
<td>201,4</td>
</tr>
<tr>
<td><strong>Sum</strong></td>
<td>7200</td>
<td>73194,6</td>
<td>12946,6</td>
<td>82154</td>
<td>66645,6</td>
<td>242141,0</td>
<td>40652,4</td>
</tr>
</tbody>
</table>

*Table 13. Total cost of the energy results without battery.*

The total cost for the energy flow in the solar panel system when the battery is not in the equation can be seen in table 13. The cost for the total energy flow is 201488,6 SEK.
5.3.2. Results for solar panel system with battery

<table>
<thead>
<tr>
<th>Month</th>
<th>Consumption kWh</th>
<th>Max Solar production kW</th>
<th>Max Overflow kWh</th>
<th>Max Out from grid kW</th>
<th>Max Saved Energy kWh</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jan</td>
<td>21243,0</td>
<td>68,0</td>
<td>1253,7</td>
<td>41,1</td>
<td>10,0</td>
</tr>
<tr>
<td>Feb</td>
<td>18922,0</td>
<td>71,0</td>
<td>3042,8</td>
<td>47,4</td>
<td>89,8</td>
</tr>
<tr>
<td>Mar</td>
<td>19507,0</td>
<td>61,0</td>
<td>7138,5</td>
<td>59,1</td>
<td>954,6</td>
</tr>
<tr>
<td>Apr</td>
<td>19937,0</td>
<td>59,0</td>
<td>9941,4</td>
<td>62,5</td>
<td>1848,1</td>
</tr>
<tr>
<td>May</td>
<td>16569,0</td>
<td>50,0</td>
<td>12366,3</td>
<td>66,5</td>
<td>3807,7</td>
</tr>
<tr>
<td>Jun</td>
<td>13449,0</td>
<td>42,0</td>
<td>12526,6</td>
<td>61,6</td>
<td>4562,5</td>
</tr>
<tr>
<td>Jul</td>
<td>12999,0</td>
<td>43,0</td>
<td>11332,3</td>
<td>60,3</td>
<td>3513,8</td>
</tr>
<tr>
<td>Aug</td>
<td>13626,0</td>
<td>47,0</td>
<td>9855,5</td>
<td>61,6</td>
<td>3149,6</td>
</tr>
<tr>
<td>Sep</td>
<td>16877,0</td>
<td>56,0</td>
<td>7689,8</td>
<td>57,5</td>
<td>1663,8</td>
</tr>
<tr>
<td>Oct</td>
<td>21350,0</td>
<td>67,0</td>
<td>4319,4</td>
<td>47,7</td>
<td>323,3</td>
</tr>
<tr>
<td>Nov</td>
<td>21604,0</td>
<td>66,0</td>
<td>1967,3</td>
<td>46,6</td>
<td>104,6</td>
</tr>
<tr>
<td>Dec</td>
<td>23284,0</td>
<td>72,0</td>
<td>1063,5</td>
<td>41,3</td>
<td>18,6</td>
</tr>
<tr>
<td>Sum</td>
<td>219367,0</td>
<td>82497,2</td>
<td>20046,5</td>
<td>159345,2</td>
<td>62450,70</td>
</tr>
</tbody>
</table>

**Table 14. Energy results with battery.**

The saved energy increased when the battery was used, which can be seen in table 14. The difference between the max consumption and the max energy from the three-phase grid is bigger in this case. It is almost a difference on 14 kW for each month, which was the goal in this project.
Table 15. Saved cost for the energy results with battery.

Table 16. Total cost for the energy results with battery.

The total saved cost did also increase when the battery was used. With the battery will Ekoxen save up to 111462 SEK, which can be seen in table 15.

Table 16 does then show that the total cost for the energy flow decreased when the battery was used. The total cost was then in this scenario 180793 SEK.
6. Discussion

6.1. Results

The graphs and the tables will be discussed further in the coming chapters.

6.1.1. The results of Time-of-Use spreadsheet tool simulation

Here will the results be discussed for the time-of-use estimation and from the modbus feature from the spreadsheet tool. The time intervals were set after condominium compound Ekoxen's consumption according to figure 10. The tests showed that it would be best to have different power flows and different charge / discharge times for the summer months than for the rest of the year. That is because of the increased amount of sun hours during June, July and August. The days are longer and the irradiation from the sun is higher. It also causes the consumption to be a lot less during the summer months.

6.1.1.1 Results for the winter months

During the winter months was the power flow coefficients set for the time-intervals between 22:00 - 06:00, 09:00-10:00, 15:00-16:00 and 16:00-22:00 and during the other intervals the power flow was set to 0 according to table 3.

The batteries were charged with a relatively high power flow during the night due to lack of solar power. Tests with lower power flow coefficients during this time-interval was made, but that did just lead to a lower reducing of the top peak because the batteries did not have enough of saved energy. During testing it was noticed that if the batteries charged during the day the consumption from the three-phase grid would increase to much higher peaks, higher peaks than the reduced peaks during the evening. This would not occur in the summer because of the high solar power. There was no need to discharge during the morning and during midday although there are some peaks at those times due to much larger peaks during the evening. In figure 30 does a peak occur, in day 17, at 55 kW. That peak was made by charging the battery, but it was almost the lowest peak for the consumption.

The biggest issue with the regulation in the winter is that the accessible energy is a lot less than in the summer month. During the shortest day the accessible energy is as low as 71.1 kWh, 35% of total energy storage. This makes it impossible to discharge with 14 kW during the whole interval at the evening. This results in an empty energy storage during 21:00-22:00 in November, December and January. As seen in figure 32 for January the batteries are fully charged but there is still a short period when the batteries are fully discharged.

According to table 4 was the maximum power from the three-phase grid reduced with 14 kW in all winter months. In the summer months was it reduce with 9.2, 13.2 and 8.2 kW which was for June, July and August. The main goal was to reduce with 1666 SEK for each month but in the summer months could that not be done.

6.1.1.2 Results for the summer months

During the summer months were the power flow coefficients for the time-intervals set between 22:00 - 06:00, 06:00 - 9:00, 09:00-10:00, 12:00 - 15:00, 15:00-16:00 and 16:00-22:00 and during the other interval the power flow was set to 0 according to table 5.
It was a lot of solar power during the summer months which resulted with reducing the power flow from 70% to 57% during the night. That made the batteries more useful. As seen in figure 31, the batteries were fully charged during a long period of the day, form around 10:00 - 16:00 in July. This was when the batteries charged with the winter mode setting during the night and compared to 13% less charging during night and more discharging during the day, which resulted with that the solar power could be used in a more efficient way. Figure 39 shows the battery behavior for July, it is noticeable to see which days there are less solar power and due to lower charging during the night and more discharging during the day it may result in an empty energy storage. However, these settings were very ineffective for the winter, figure 40 shows the battery behavior during January and as shown, the batteries are only charged to around 90% during the night. This makes it unsafe, because the peaks come at the evening.

According to table 6 did the time-of-use program manage to reduce the maximum power from the three-phase grid an average of 11,89 kW in the winter months compared to 14 kW for the winter mode settings. In the summer months was it reduce with an average 12,23 kW compared to the winter mode settings with an average of 10,2 kW

6.1.2. The modbus feature results

In the testing of the modbus feature was the battery set to charge during almost all time-intervals except for the time interval-between 16:00 - 22:00. The power flow coefficients was set to 60% during 06:00 - 16:00. Between 22:00-06:00 was it set to 50% and for the time-interval between 16:00-22:00 was it set to 100%. Maximum power flow is 14 kW.

The energy flow diagrams for July and January in figure 42 and 43 is a bit different. In figure 42 does the battery almost charge constantly, that is because the overflow comes so early in the day. In figure 42 does the battery discharge around 08:00, the reasons are that the energy from three-phase grid is higher than the $P_{three\text{-phase grid, mean}}$ and $P_{three\text{-phase grid, max}}$.

In figure 45 does it seem that the peak is the same for every day in July. The battery gets charged more during the end of July, because of the solar power. Figure 49, 50 and 51 shows the peak reduction, the battery managed to shave the peaks with 16 and 14 kW for each month. It did not work with 18 kW for each month. In August did the energy regulation reduce the highest peak with 12.7 kW and in the other months it is closer to approximately 18 kW.

6.1.3. The energy flow and cost results

The total saved cost for using only solar energy was 90767,3 SEK according to table 12 and the total saved cost for using battery and solar energy was 111462,3 SEK.

The saved cost of using only the battery will be 111462,3 - 90767,3 = 20695 SEK.
6.2. Method

Time-of-use was complicated to configure during the modeling of PPAMs battery. It was hard to understand how the ratio between the peak cost was related to what power flow it used. It sometimes worked very randomly. The functions that the inverter followed had to be known from start to even get a hint of why it controlled the energy flow in the way it did. If the method started with doing a modbus program, then the project would have time to implement it. However, the Time-of-use program (SMA Solar Technology, version 11) is easier to understand than a programming language as modbus.

The energy flow simulation was done in the spreadsheet tool. All hour values for the consumption and for the solar production was inserted there. The solar energy production values were simulated in PVsyst (PVsyst). This tool got four sheets. One sheet with the solar power production, a second sheet with the results from the energy flow without the battery, a third sheet with the results from the energy flow with the battery and the in the last one was all the measurements / diagrams shown. This could not have been shown easier.

From the beginning was it hard to understand why the energy flow simulation had to be done in a spreadsheet tool, but that was what PPAM wished for. Other simulation tools as matlab would have been easier to handle if the energy flow calculations were implemented there, because that program is already programmable-friendly, and the results is already shown in tables. In the spreadsheet tool was the energy flow simulations done in macros and it was the first time any of the authors used it.

The consumption and the solar energy production values are calculated related to the reality. It is hard to say how high reliability the modbus feature has, because it has not been tried on batteries in reality. The consumption profile is although very reliable, because it is measured from Ekozen's fuse limit. In other hand, the solar energy production can differ from the reality, the inputs to PVsyst is the amount of sun irradiation, number of solar panels, inverters etc. That means that the simulation gets inputs that can differ with the reality in the beginning.

6.2.1. Source criticism

IEEE was the database that was used most. It is used by many electrical engineers, from new graduates to professors for sharing researches from the electrical industry. It felt obvious to use the internet to find sources to this thesis, because the technology is pretty new and it felt easier. Some of the used sources are criticized below, partly to give proof of that IEEE is a trustful database.

The source that was used most in this thesis was Teja and Yemulas report which was about how to control the energy flow in a solar panel system with a battery storage. Teja and Yemula wrote this report in 2016 and at that time did they work in the electrical department at the Indian Institute of Technology Hyderabad. Their thesis explained much about how each part in the energy flow system could be calculated and it felt very logical and easy to understand. Their report felt trustworthy because they have a degree in electrical engineering and that the report was only two years old. Their thesis is a second-hand source, but from looking in the reports from their reference list does it seem like they have taken the most
relevant parts. The sources they have used does also come from IEEE, which makes their report more trustworthy.

IEEE was also used to find information about on how to peak shave the consumption curve. Here was A. Rahimi, M. Zarghami, M. Vaziri and S. Vadhva thesis used. The thesis was written in 2013. A. Rahimi got his bachelor’s degree in power systems back in 2012 at California State University, Sacramento. In 2013 did he pursue his studies to get a master’s degree in power systems. M. Zarghami got his Ph.D. degree in electrical engineering from Missouri University of Science and Technology, USA in 2008. He also has 15 years of industrial experience. M. Vaziri got his Ph.D. degree in 2000 from WSU, Pullman WA. He is a senior member of the IEEE and he is currently involved in the research of integrating renewable energy sources. S. Vadhva got his Ph.D. degree in 1982 from University of New Mexico. They use references from IEEE which makes their report more trustworthy.

The thesis did also use information from SMA datasheet. They were mostly used because of that Ekoxen used their AC/DC inverters. It does not say when the datasheets were made but each of them got a version number. They should be trustworthy because it is their own inverters they explain and that SMA is a well-known trademark in the renewable energy industry.
6.3 Work in a broader context

An ethical analysis was made for the solar panel systems to see what consequences they can give. For the analysis, a table of the advantages and disadvantages for solar panel systems were made. A discussion of how the solar panel systems will be used in the future, a so called instant moment scenario was also made (Hansson, 2009).

<table>
<thead>
<tr>
<th>The use of solar panel systems</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Advantages</strong></td>
<td><strong>Disadvantages</strong></td>
</tr>
<tr>
<td>The energy cost for households will be lower</td>
<td>Solar panels can take a lot of space</td>
</tr>
<tr>
<td>Does not harm the nature under the production of solar power.</td>
<td>They cannot produce the same amount of energy in every condition.</td>
</tr>
<tr>
<td>Can be used as noise protection</td>
<td>Installing costs of solar panels can be very high</td>
</tr>
<tr>
<td>Can be used for blocking the sun</td>
<td>Weather-dependent</td>
</tr>
<tr>
<td>Can be used to take advantage of energy in remote places.</td>
<td>Still an unknown technic to some extent</td>
</tr>
<tr>
<td>Almost maintenance free</td>
<td>Waste disposal</td>
</tr>
</tbody>
</table>

*Table 17. Advantages and disadvantages of using solar panel systems.*

People or companies that uses solar panel systems are often those that care for the environment, but it can also be those that only want to save and earn money. This can lead to that people are installing their solar panel systems at places where they are unwanted.

In ten years from now will there be more electrical cars on the roads, more people will know the environmental challenges. The use of renewable energy will be a very big interest and the cost of solar panels will probably be lower than now. Due to the increase of solar panels around the world the waste disposal becomes more important to do correctly. Small communities/villages that are isolated such as in developing countries can now have a self-sufficient electricity grid. This leads to less carbon dioxide emissions and better health for those who can replace wood burning stoves against induction cooktops.

Based on the future analysis, it was seen that several ethical challenges from increased use and development of solar cells were presented.

- Should it be ethically justifiable not to use solar cells in the future as it is better for the environment than to use fossil fuels?
- How will the development of solar cells affect the developing countries with the most radiation, will these countries be taken advantages of in the wrong way?
7. Conclusion
The method changed focus somewhere in the middle of the project. From the start there were more focus on making a regulation technique simulation tool for an implementation in modbus but later on PPAM became more interested in making the simulation tool for Time of use. Although two methods of the focused problem on how the energy storage would be regulated have been simulated. Due to delays of installation of the solar panels at condominium compound Ekoxen there was more focus on the simulation tool rather than real results.

To achieve the best result when using Time of use, the power flow coefficients and the charging/discharging times would have to be changed two times a year. One period for the summer months and one period for the rest of the months. Although the power peak reduction in the summer months were not as good as in the winter months it is probably worth doing. The batteries would last longer and not be as wearied out due to lower power flows. Ekoxen's solar panels were estimated to produced 82500 kWh and 20000 kWh were sold to the grid. If the sold energy would exceed 30000 kWh, then they would lose the tax revenue on every kWh above that limit. This is another benefit from changing the coefficient so that as much solar power is feed in to the batteries as possible. An implementation in modbus would be the best option. The power flow can be lower during night time and no changes of coefficient would be necessary.

Due to the accessible energy changes over the year and that the power flow was needed to be set to maximum from as early as 16:00-17:00 due to Ekoxen's consumption profile the result shows that the energy storage was empty at some points during the night, around 21:00 in the darkest months of the year. This did not make a negative impact on the simulations although there were medium-high peaks around those hours. If the spreadsheet tool had used another consumption profile than the one that are used in this project, then the simulation results would not be the same. A possible solution to this is either to increase the battery storage capacity or to lower the power flow.
8. References


9. Appendix

9.1. Appendix 1 - Simulation program

Below follows the code for the simulation program that was implemented in Visual basic (excel).

Public CalcState As Long
Public EventState As Boolean
Public PageBreakState As Boolean

Dim maxload As Double
Dim gridout As Double
Dim h_month As Variant
Dim ebatuse As Double
Dim ebatmin As Double
Dim overflow As Double
Dim maxpowerflow As Double
Dim tid As Integer
Dim solp As Double
Dim kons As Double
Dim ebatold As Double
Dim powerflow As Double
Dim a As Integer
Dim x As Integer
Dim y As Integer
Dim z As Integer
Dim k As Integer
Dim j As Integer
Dim i As Integer
Dim q As Integer
Dim peakshave As Boolean
Dim days As Integer
Dim grid_tot As Double
Dim loss As Double
Dim grid_medel As Double
Dim grid_max As Double
Dim grid_test As Double
Dim battery_lasthour As Double
Dim ebatnew As Double
Dim efficiency As Double
Dim overflow_test As Double
Dim maxkonsdag As Double
Dim maxgriddag As Double
Dim maxgriddag_solar As Double
Dim period1_a As Double
Dim period1_n As Double
Dim period2_a As Double
Dim period2_n As Double
Sub Regfunc()

Call OptimizeCode_Begin

Worksheets("Main").Activate
ebatmax = Cells(21, 2).Value
maxpowerflow = Cells(22, 2).Value
efficiency = Cells(23, 2).Value

period1_a = Cells(35, 2).Value
period1_n = Cells(35, 3).Value
period2_a = Cells(36, 2).Value
period2_n = Cells(36, 3).Value
period3_a = Cells(37, 2).Value
period3_n = Cells(37, 3).Value
period4_a = Cells(38, 2).Value
period4_n = Cells(38, 3).Value
period5_a = Cells(39, 2).Value
period5_n = Cells(39, 3).Value
period6_a = Cells(40, 2).Value
period6_n = Cells(40, 3).Value
period7_a = Cells(41, 2).Value
period7_n = Cells(41, 3).Value

ebatmin = 0
h_month = Array(743, 671, 743, 719, 743, 719, 743, 743, 719, 743, 719, 743)

maxgriddag = 0
maxkonsdag = 0
maxgriddag_solar = 0
grid_tot = 0
grid_medel = 100
grid_max = 0

i = 4
k = 0
x = 0
y = 0
z = 0
j = 0
days = 0
q = 24
Worksheets("Battery_calc").Activate
peakshave = Cells(21, 34).Value
ebatuse = (ebatmax * 0.35) + 10 * ebatmax * (0.2 / 182.5)
While (i < 8764) '8764

    tid = Cells(i, 3).Value
    solp = Cells(i, 4).Value
    kons = Cells(i, 5).Value
    ebatold = Cells(i - 1, 7).Value

    powerflow = 0
    loss = 0
    gridout = 0
    overflow = 0
    a = 0
    gridout = gout(kons, solp)
    overflow = overf(kons, solp)

    grid_tot = grid_tot + gridout

    If k = 23 Then
        grid_medel = grid_tot / 24
        grid_tot = 0
        k = 0
        Cells(days + 3, 25).Value = ebatuse
    End If

    k = k + 1

    If days < 172 And q > 23 Then
        ebatuse = ebatuse + ebatmax * (0.2 / 182.5)
        q = 0
        days = days + 1
    ElseIf days > 353 And q > 23 Then
        ebatuse = ebatuse + ebatmax * (0.2 / 182.5)
        q = 0
        days = days + 1
    ElseIf q > 23 Then
        ebatuse = ebatuse - ebatmax * (0.2 / 182.5)
        q = 0
        days = days + 1
    End If
\[ q = q + 1 \]

If \((tid <= 6) \text{ Or } (tid >= 23)\) Then

\[ a = \text{period1}_a \]
\[ n = \text{period1}_n \]
\[ \text{powerflow} = \text{maxpowerflow} \times n \]
If peakshave = True Then
\[ \text{powerflow} = \text{powerflow}_\text{calc}(\text{gridout}, \text{grid.medel}, \text{grid.max}) \]
End If
\[ \text{ebatnew} = \text{calc}(\text{gridout}, \text{overflow}, \text{ebatold}, \text{powerflow}, \text{ebatuse}, a) \]

ElseIf \((tid >= 7) \text{ And } (tid < 10)\) Then

\[ a = \text{period2}_a \]
\[ n = \text{period2}_n \]
\[ \text{powerflow} = \text{maxpowerflow} \times n \]
If peakshave = True Then
\[ \text{powerflow} = \text{powerflow}_\text{calc}(\text{gridout}, \text{grid.medel}, \text{grid.max}) \]
End If
\[ \text{ebatnew} = \text{calc}(\text{gridout}, \text{overflow}, \text{ebatold}, \text{powerflow}, \text{ebatuse}, a) \]

ElseIf \((tid = 10)\) Then

\[ a = \text{period3}_a \]
\[ n = \text{period3}_n \]
\[ \text{powerflow} = \text{maxpowerflow} \times n \]
If peakshave = True Then
\[ \text{powerflow} = \text{powerflow}_\text{calc}(\text{gridout}, \text{grid.medel}, \text{grid.max}) \]
End If
\[ \text{ebatnew} = \text{calc}(\text{gridout}, \text{overflow}, \text{ebatold}, \text{powerflow}, \text{ebatuse}, a) \]

ElseIf \((tid >= 11) \text{ And } (tid < 13)\) Then

\[ a = \text{period4}_a \]
\[ n = \text{period4}_n \]
\[ \text{powerflow} = \text{maxpowerflow} \times n \]
If peakshave = True Then
\[ \text{powerflow} = \text{powerflow}_\text{calc}(\text{gridout}, \text{grid.medel}, \text{grid.max}) \]
End If
\[ \text{ebatnew} = \text{calc}(\text{gridout}, \text{overflow}, \text{ebatold}, \text{powerflow}, \text{ebatuse}, a) \]

ElseIf \((tid >= 13) \text{ And } (tid < 16)\) Then

\[ a = \text{period5}_a \]
\[ n = \text{period5}_n \]
\[ \text{powerflow} = \text{maxpowerflow} \times n \]
If peakshave = True Then
\[ \text{powerflow} = \text{powerflow}_\text{calc}(\text{gridout}, \text{grid.medel}, \text{grid.max}) \]
End If
ebatnew = calc(gridout, overflow, ebatold, powerflow, ebatuse, a)

ElseIf (tid = 16) Then
    a = period6_a
    n = period6_n
    powerflow = maxpowerflow * n
    If peakshave = True Then
        powerflow = powerflow_calc(gridout, grid_medel, grid_max)
    End If
    ebatnew = calc(gridout, overflow, ebatold, powerflow, ebatuse, a)

ElseIf (tid >= 17) And (tid < 23) Then
    a = period7_a
    n = period7_n
    powerflow = maxpowerflow * n
    ebatnew = calc(gridout, overflow, ebatold, powerflow, ebatuse, a)
End If

grid_test = kons - solp + (ebatnew - ebatold) + a * (ebatnew - ebatold) * (1 - efficiency) '0 = Gridout-konsumtion+solprod-överskott-(newbattery-oldbattery)
overflow_test = 0

If (grid_test <= 0) Then
    overflow_test = grid_test * -1
    grid_test = 0
End If

If x > h_month(z) Then
    grid_max = grid_max * 0.67
    x = 0
    z = z + 1
End If

x = x + 1

If grid_test > grid_max Then
    grid_max = grid_test
End If

If kons > maxkonsdag Then
    maxkonsdag = kons
End If

If grid_test > maxgriddag Then
    maxgriddag = grid_test
End If
If gridout > maxgriddag_solar Then
    maxgriddag_solar = gridout
End If

If j = 23 Then
    Cells(days + 3, 26).Value = maxkonsdag
    Cells(days + 3, 27).Value = maxgriddag
    Cells(days + 3, 28).Value = maxgriddag_solar
    maxgriddag = 0
    maxkonsdag = 0
    maxgriddag_solar = 0
    j = 0
End If

j = j + 1

Cells(i, 7).Value = ebatnew
Cells(i, 17).Value = ebatuse
Cells(i, 19).Value = grid_test
Cells(i, 20).Value = grid_medel
Cells(i, 21).Value = grid_max

i = i + 1

Wend
Call OptimizeCode_End
Worksheets("Main").Activate
End Sub

Function gout(kons As Double, solp As Double) As Double  'räknar ut energin från trefasnätet
    gout = 0
    gout = kons - solp
    If (gout < 0) Then
        gout = 0
    End If
End Function

Function overf(kons As Double, solp As Double) As Double  'räknar ut överskottet
    overf = 0
    overf = solp - kons
    If (overf < 0) Then
overf = 0

End If
End Function

Function calc(gridout As Double, overflow As Double, ebatold As Double, powerflow As Double, ebatuse As Double, a As Integer) As Double ' Test 1 overflow = 0, gout /= 0, kl 11. // Test 2 overflow = 9.42 kW, gout = 0, kl 7
Dim y As Double

If (overflow >= powerflow) Then
    y = megaoverflow(gridout, overflow, ebatold, powerflow, ebatuse, a)
calc = y
ElseIf (overflow > 0 And overflow < powerflow) Then
    y = minioverflow(gridout, overflow, ebatold, powerflow, ebatuse, a)
calc = y
Else
    y = noneoverflow(gridout, overflow, ebatold, powerflow, ebatuse, a)
calc = y
End If
End Function

Function megaoverflow(gridout As Double, overflow As Double, ebatold As Double, powerflow As Double, ebatuse As Double, a As Integer) As Double
If a = -1 Then
    If overflow < maxpowerflow * 0.5 Then
        powerflow = overflow
    Else
        powerflow = maxpowerflow * 0.5
    End If
End If
End Function

If a = 1
If (ebatold > ebatuse - (powerflow * efficiency ^ a)) Then
    ebatnew = ebatold + (a * (ebatuse - ebatold) * efficiency ^ a)
Else

ebatnew = ebatold + (a * powerflow * efficiency ^ a)

End If

megaoverflow = ebatnew

End Function

Function minioverflow(gridout As Double, overflow As Double, ebatold As Double, powerflow As Double, ebatuse As Double, a As Integer) As Double

If (ebatold > ebatuse - (powerflow * efficiency ^ a)) Then

If (a = -1) Then

If ((powerflow * efficiency ^ a) > (ebatuse - ebatold)) Then

    ebatnew = ebatold + (a * (ebatuse - ebatold) * efficiency ^ a)

Else

    ebatnew = ebatold + (a * overflow * efficiency ^ a)

End If

Else

If ((ebatuse - ebatold) <= (powerflow * efficiency ^ a)) Then

    ebatnew = ebatold + (a * (ebatuse - ebatold) * efficiency ^ a)

Else

    ebatnew = ebatold + (a * (ebatuse - ebatold) * efficiency ^ a)

End If

End If

Else

If (a = -1) And (ebatold < overflow) Then

    ebatnew = ebatold

ElseIf (a = -1) Then

    ebatnew = ebatold + (a * overflow * efficiency ^ a)

Else

    ebatnew = ebatold + (a * powerflow * efficiency ^ a)

End If

End If

Else

If (a = -1) And (ebatold < overflow) Then

    ebatnew = ebatold

ElseIf (a = -1) Then

    ebatnew = ebatold + (a * overflow * efficiency ^ a)

Else

    ebatnew = ebatold + (a * powerflow * efficiency ^ a)
End If
End If

minioverflow = ebatnew

End Function
Function noneoverflow(gridout As Double, overflow As Double, ebatold As Double, powerflow As Double, ebatused As Double, a As Integer) As Double

If (ebatold > ebatused - (powerflow * efficiency ^ a)) Then

If (a = -1) Then

If (gridout < (powerflow * efficiency ^ a)) Then

ebatnew = ebatold + (a * gridout * efficiency ^ a)

Else

ebatnew = ebatold + (a * powerflow * efficiency ^ a)

End If

Else

ebatnew = ebatold + (a * (ebatused - ebatold) * efficiency ^ a)

End If

Else

If (ebatold < (powerflow * efficiency ^ a)) And a = -1 Then

powerflow = ebatold * efficiency

End If

If (gridout < (powerflow * efficiency ^ a) And a = -1) Then

powerflow = gridout * efficiency

ebatnew = ebatold + (a * powerflow * efficiency ^ a)

Else

ebatnew = ebatold + (a * powerflow * efficiency ^ a)

End If

End If

End If
noneoverflow = ebatnew

End Function

Function powerflow_calc(gridout As Double, grid_medel As Double, gridmax As Double) As Double 'topeffekt hacks

powerflow = maxpowerflow * n

If gridout >= (grid_medel + maxpowerflow) And (ebatold > (ebatuse * 0.5)) Then
    a = -1
    powerflow = (gridout - (grid_medel + maxpowerflow))
    If powerflow >= maxpowerflow Then
        powerflow = maxpowerflow
    End If
    If powerflow < maxpowerflow * 0.4 Then
        powerflow = maxpowerflow * 0.4
    End If
ElseIf (gridout + powerflow) >= gridmax And (ebatold >= ebatuse - powerflow) Then
    a = -1
    n = 0.5
    powerflow = maxpowerflow * n
ElseIf (gridout + powerflow) >= gridmax And a = 1 Then
    n = 0.1
    powerflow = maxpowerflow * n
End If

powerflow_calc = powerflow

End Function

Sub OptimizeCode_Begin()

Application.ScreenUpdating = False

EventState = Application.EnableEvents
Application.EnableEvents = False

End Sub
CalcState = Application.Calculation
PageBreakState = ActiveSheet.DisplayPageBreaks
ActiveSheet.DisplayPageBreaks = False

End Sub

Sub OptimizeCode_End()

ActiveSheet.DisplayPageBreaks = PageBreakState
Application.Calculation = CalcState
Application.EnableEvents = EventState
Application.ScreenUpdating = True

End Sub