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RURAL ISOLATED MINI-GRID WITH PHOTOVOLTAIC SUPPLY IN CHIFUNDA (ZAMBIA)

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Abstract

The energy demand in developing countries is increasing and many villages in these countries do not even have a connection to the national grid. Therefore, they use kerosene and candles for lighting their homes at night and batteries for supplying their electrical devices. With renewable energy sources a minigrid can be built up anywhere to cover the demands. The village in which the project will be conducted is near the equator and therefore a photovoltaic system provides a good opportunity for the energy supply.

This thesis approaches the whole planning for an electrification of a village in Zambia, which is called Chifunda. In this area about four-hundred households need to be supplied and also the demands of other buildings like a mill, a school, a hospital and different shops need to be covered. Nearly the whole energy will be supplied by the photovoltaic- and the storage system, but a small part still need to be covered by a backup generator.
The demand of the village is predefined and so there will be two options introduced. First, the needs are reduced to the essential parts and the system will be calculated to supply this amount of energy.
The second option is to cover nearly the whole energy needs with the photovoltaic- and the storage system. For the whole planning of the electrification the dimensioning of the system parameters is important and also the electrical protection of the system has a significant role.

The whole calculations and analysis have been done with the program PVsyst. For the calculation of the storage system, it was necessary to export different data to Excel. Therefore, a program had to be written which can compute the state of charge of the battery, the energy which is needed from an external source and the lost energy which is due to a full battery. With the help of this program it was possible to calculate if the sizing of the system was sufficient.
Therefore, the different options have been compared and analysed to get the cheapest and most sustainable solution.

Keywords: renewable energies, photovoltaic, rural electrification, storage system, sustainability

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1 Introduction

1.1 Scope of this project

The purpose of this project is to design a photovoltaic (PV) system which can provide electrical supply to four hundred households. The system is located in Zambia in the village Chifunda. The emphasis of this project is the dimensioning and planning of the whole PV system and the integration of a battery system. Furthermore, the analysis of the energy consumption and optimization suggestions have a significant role. Additionally, there is an analysis of rural electrification and how optimization can be realized. The electrical power needs for each house are 150 watts, which will cover their basic energy needs like lighting, entertainment (TV) and the operation of simple hand-tools and appliances. Moreover, there is a mill to grind cereals, a school and a hospital, which will be advantageous supplied with energy in comparison to the households.

Therefore, the objectives are:

- To supply electricity to the isolated village
- To minimize cost
- To specify all system components such as PV panels, batteries, inverters and Conductors

1.2 Aims

As part of this work there appear different questions which will be analysed and processed.

- How can the user needs be covered and optimized?

The whole user needs are given by the village and they must be covered nearly until entireness. The rest will be contributed by a backup system. So, a detailed consumption analysis will be necessary. First of all, a reduction of these needs, to the minimum amount which is possible, will be the first step for calculating the system. This step can be crucial to keep the costs for the system in a suitable frame. Afterwards, the system size will be increased to supply nearly the whole energy needs. From all the demands, the ones of the school, mill and hospital are the most important ones. So, when the energy consumption of these buildings is covered, the households will be supplied. How the different hours of consumption affect the state of charge of the battery will be also analysed. Preferable the hours with sun irradiation shall be the hours in which the most energy is consumed. This is hard to realise because at night much energy is used for lighting and entertainment.

- How should the system be dimensioned?

There will be an analysis of the location and also of the system components. For the dimensioning, the program PVsyst will be used. The important system components, the inverters and the PV panels are already predefined, so they do not have to be researched. The analysis will be needed to find out the ideal possible orientation, the number of panels in serial and parallel and also the numbers of batteries. It is not possible to implement the batteries in PVsyst and so it will be needed to introduce the data in Excel and to calculate the charge and discharge process there. Moreover, there will be an implementation of all necessary losses which affect the system. These losses are crucial to know to be aware of the real amount of energy which is supplied by the PV panels. Furthermore, there will be a shadowing analysis to make sure that the system is working in optimal conditions. The safeguards also play a significant role and must be implemented in the system to get the maximal available security. Therefore, lightning protection, high voltage protection, string protection and a load break switch will be important. The wiring and how it will be accomplished is relevant because there will be different possibilities. Therefore, it is necessary to choose the cheapest and most efficient one.

2 Fundamentals about the location

The location of Chifunda is situated in Zambia in the south of Afrika which is in the south of the Equator. The distance to the Equator amounts to 1338 km, which was calculated by “date and time” (dateandtime.info, 2017)

The geographical area of Zambia ranges in total 752618 sq km. The population is about 16,21 million people and the village Chifunda is located in the east province of Zambia. It has just got a few inhabitants and is not connected to the national grid.

The Economy of Zambia is dependent on the copper price, because they are a very big copper exporter. A big environmental problem here plays the air pollution and the resulting acid rain in the mineral extraction and refining regions.

In Figure 1 can be seen how the allocation of the energy consumption, production, import and export in the year 2014 was. It can be noted that even more energy is produced then consumed and this country has got a very little amount of import, in comparison to the other factors.

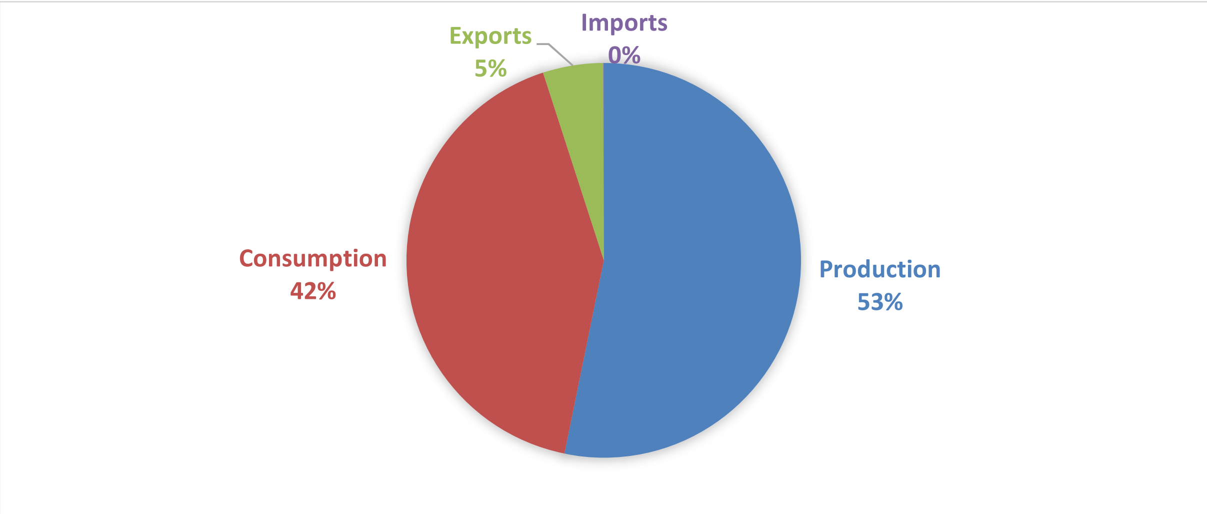

Figure 1 Energy in Zambia (Central Intelligence agency, 2014)

2.1 Climate, weather and location

Chifunda is located in the eastern province of Zambia. Zambia has got ten provinces and this is eastern province is one of them. This province is divided in nine districts and the village is located in Lundazi.
The weather in Zambia is mostly tropical, but it is also crossed through by some rainy seasons. In the time of the rainy seasons tropical storms can occur and in the other time of the year periodic droughts.
(Central Intelligence agency, 2014)

In Figure 2 the village Chifunda and the location of the PV panels can be seen. The panels will be located behind an airplane landing field, but there are also the options to set the location of the panels a bit more into the back. Therefore, it would be necessary to cut a few trees to ensure sufficient sunlight on the panels. Furthermore, the village is very spread so there is not a real centre of the town. This complicates the energy supply because longer conductors will be needed and so the losses will be increased. Also, a suggestion for the location of the battery system has been made, which is 500 metres away from the powerplant. On the way energy can be supplied to the users in the surrounding.

Figure 2 location in Chifunda (Google Earth)

The next major city, for which metrological data is available, is the city Mpika. As we can see in Figure 3 Chifunda is located about 104 km in the south-east of Mpika. So, it can be assumed that the climate and weather will be nearly the same.

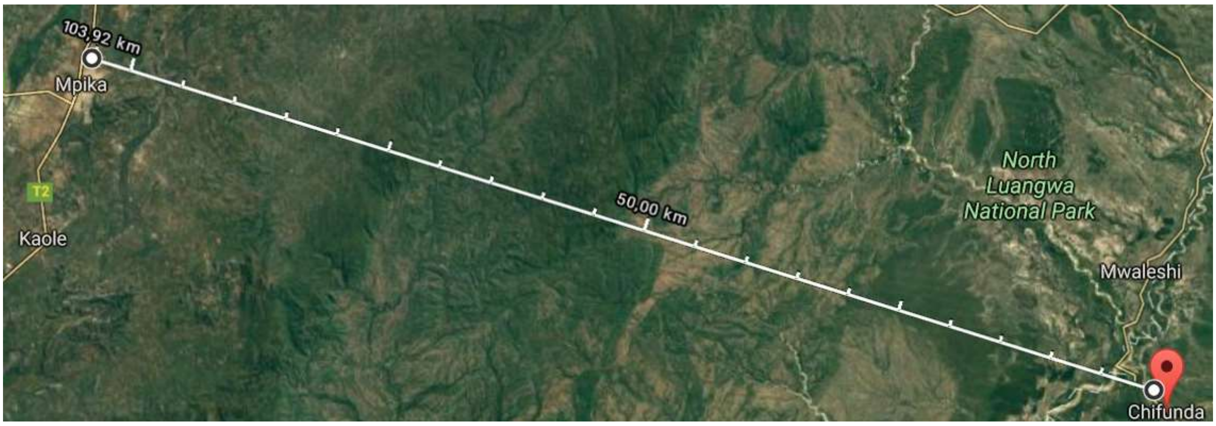

Figure 3 location Chifunda and Mpika (google.maps.com)

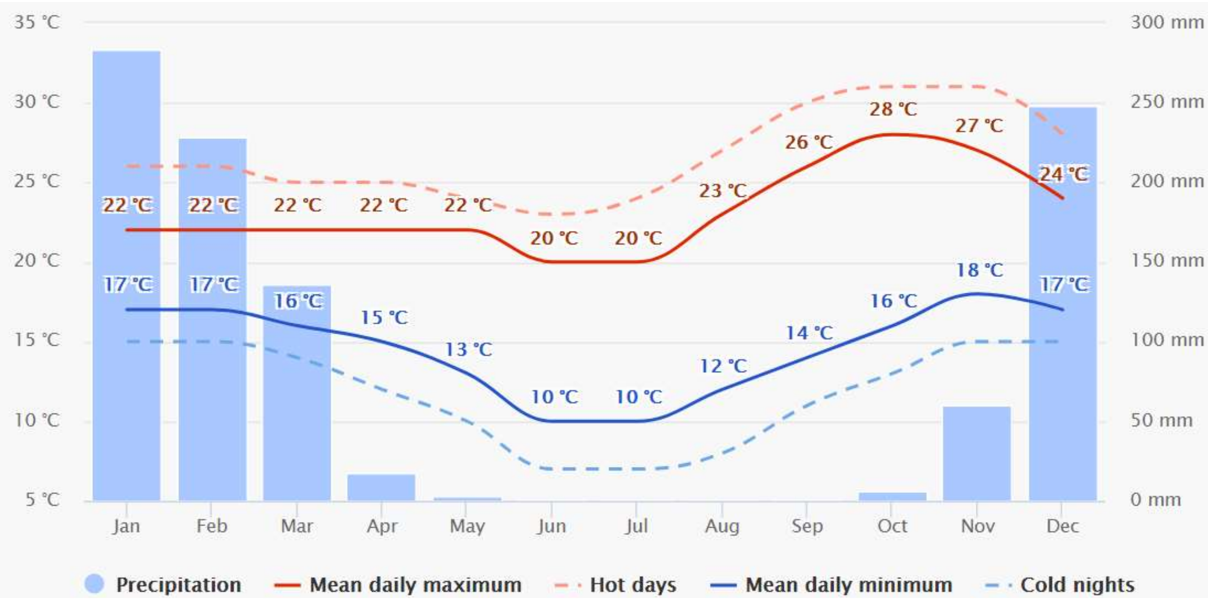

Figure 4 Temperature and rain in Mpika (meteoblue.com, 2017)

In Figure 4 it is shown that the maximum temperature fluctuation over the whole year will be from 28°C in October, to 20°C in June and July. In the hottest days, a temperature of 31°C can occur. The minimum temperature fluctuates from 18°C in November to the minimum of 10°C in June and July, which is the winter in Chifunda. In the months June and July, the coldest nights are at about 7°C but the lowest temperature which has been measured in Zambia was -1°C. Furthermore, this Graph shows that a rainy season occur in the summer months, so this must be considered when the photovoltaic system is planned. This season in Africa has also a big influence on the solar irradiation in the summer months. As we can see in "Dimensioning of the system" the solar irradiation in some summer months is even less than in the wintertime and so also the energy-production is less. We can also see in Figure 4 that the rainy season ranges from December to the end of March and has a maximum in January with 283mm/m² of rain. To be able to know how much this amount of water is there will be a comparison with Valladolid and Vienna. So, if we see it in numbers the rainiest month of Vienna is June and from Valladolid it is December. In Vienna, there is a maximum of 46mm/m² and in Valladolid a maximum of 41mm/m², these numbers in comparison to the maximum amounts of rain in Chifunda are very small. The amount is even more than five times smaller than it is in Chifunda. This can be seen if we compare Figure 5 and Figure 6. This is just a small timeframe of ten days but as we can see it here it is also a reduced energy production in the months from December to February. So, this amount of rain in the area of Chifunda like earlier mentioned will lead to less solar irradiation, so that the backup system has to produce more energy. Further information about the produced energy over the whole year can be found in the attached Excel sheet.

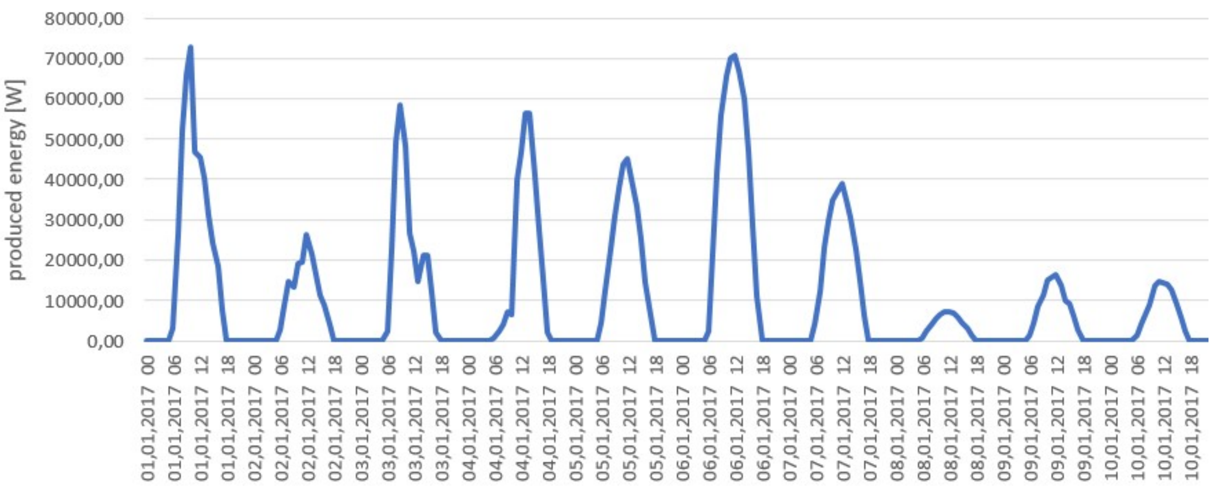

Figure 5 energy production 01.01-10.01 (own figure)

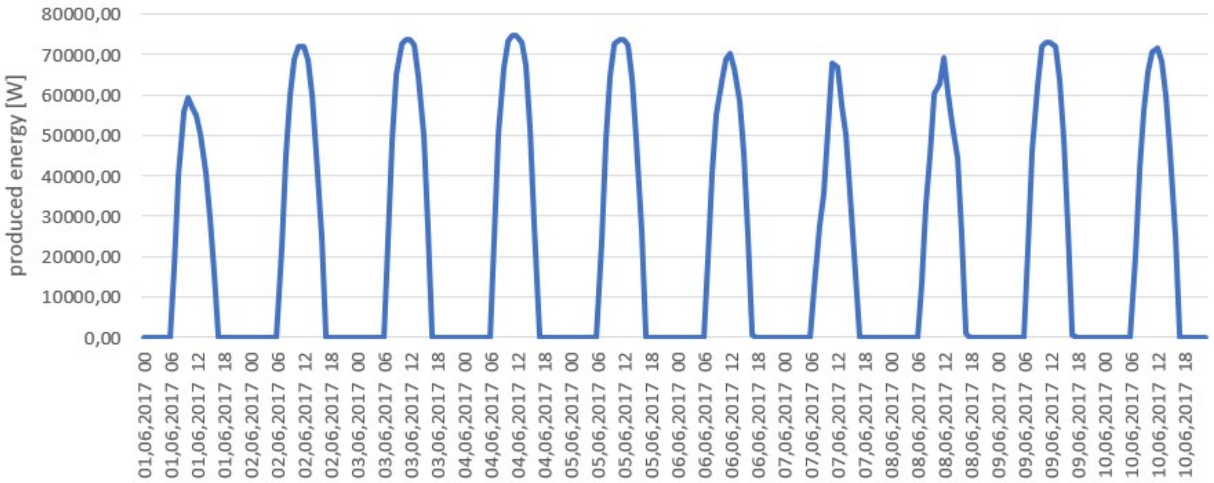

Figure 6 energy production 01.06-10.06 (own figure)

2.2 Natural catastrophes

In Zambia, different types of natural catastrophes occur, hereby floods and droughts have got a significant amount. Floods emerge not every year, but have increased in the last two decades. Floods are a serious problem, because they affect everyone who lives in the specific area. The flood season is generally from December to April. Droughts occur more often in the Southern and Western part of Zambia, till now they have been noted in the months February to April and in August. Furthermore, there is a high risk of epidemics which appear because of lack of sanitation and hygiene and also because of the poor quality of the drinking water. The air pollution has an effect on acid rain, which has an further impact on plants and animals. To work against these catastrophes, Zambia has established an institution which is called the Disaster Management and Mitigation Unit (DMMU). This institution takes effort in disaster preparedness, prevention and mitigation, while the focus is on response to disasters. The interest in disaster prevention and risk management have increased in the last years, because also the disasters have become more frequent. Generally, Zambia has not got a high risk and the most hazards occur in local areas.

(Jacobs, 2012)

3 Mini grids in rural areas

Electricity plays a big role in nowadays world. We are getting increasingly dependent on it, which does not have to be a bad thing. Nearly everybody in the western countries work day by day with electricity, even when it is not actually recognised. In developing countries, the people also want to get the benefits from electricity and so they have expanded the national grid. So, more people are getting used to the electricity, but it is not possible or very cost intense to expand the national grid into every part of the countries. When the electricity spread beyond the urban areas, the electricity use and also the costs for supplying this energy drastically increased. So, the responsible energy companies avoided further investments in these areas. Subsequently, individual communities in these parts are starting to construct their own rudimentary electricity distribution. So, the willingness of the people is given to act and involve themselves. Hydropower plants or diesel generator sets often power these mini-grids. While these options are the most cost-efficient ones, they are most of the time only improvised, inefficient and unsafe. Also, the lifespan of these mini grids suffers a lot, because there are nearly no guidelines available to build up such a grid.

In these systems, the cost really depends on the size and nature of the needed load but also on safety arrangements and the lifetime of the system. These guidelines should outline that the system is safe, adequate, expandable and efficient. Which means that the electric standards must be adhered but also the conditions in the specific rural areas have to be considered. For example, not every guideline which counts in the urban areas can be implemented into the rural areas. (NRECA-International)

Adequacy of a system means that outlets and conductors must have the right size and type. Furthermore, it means how a power system can cope with the peak loads and to be prepared for uncertainties in the availability of generation. This means that the system must ensure that it can provide the energy which is needed but also to avoid loss-of-load events.
(wind-energy-the-facts, 2008)
Expandability can be met when the used design has a minimized life cycle cost, but also that it can be expanded when the load increases by time, so that it does not have to be rewired. The efficiency of a system is dependent on different factors like the costs, which must be almost minimized in rural areas, wiring, losses and the efficiency of the power distribution system itself. There must be a compromise between quality and costs, because it is unnecessary to use low cost and low-quality products which must be replaced in a few years. When it comes to the efficiency of the power plant the costs play a significant role in this area. But sometimes it is more important to have a low-cost system with lower efficiency, than an unaffordable high efficient system.
When it comes to rural electrification there is no standard way to provide the system, because each one is different from the other. One has to be more efficient and the other one of lower cost. Here it is necessary to go back to the basic principles and to develop the system from there on to bring the people in rural areas benefits of electricity. There are different aspects which can be looked at in designing rural electrification. First of all, the grounding is most of the time not available in these mini-grids. But it can rise the security of these systems significantly, so it should be taken into account after checking the expenses and the effort. Also, there must be examined which components must be in each residence. The costs of metering and the meters themselves are most of the time quite expensive an, so the question is here how to be able to reduce these costs. Like mentioned before the type of conductor plays a big role to reduce costs but also not to have to high losses.
The distribution of such mini grids must be planned with a long-term perspective while taking a safe design and low life-cycle costs into account. It is also beneficial if some people in these areas are skilled, and are able to repair smaller parts of the system properly to reduce costs and future damages. Moreover, it is essential to teach the people how to handle the electricity and that switches and fuses are necessary and important. If this is not done safety devices are jumped and cannot longer fulfil their job. Furthermore, this will increase the life-cycle cost and also put a high risk on the user. Also, if low costs are achieved the question remains if the system is sustainable and if the community is able to pay for the system and the recurring costs.

3.1 Elements of electrification

Many steps need to be taken before acting with the construction of the system. The proper design is a critical part to go into the right direction, but a few parts are crucial for success of the project.

- The people must be interested in getting access to electricity but they also have to be able to pay for it. If the project is funded by the government or any other organisation at least the recurring costs need to be covered by the users.
- A responsible company or organization must be identified which initiates the request for the electrification and takes the managing and operating of the project.
- The availability of electricity in the vicinity must be checked to ensure the cheapest and most efficient way of electrification.

These parts of the project must be checked before initiating the process of the project to ensure a higher chance of success.

As everybody knows money is very important in this world. So, the willingness and ability to pay for the electricity must be given, otherwise it will not work. The main costs are the capital costs which occur when the system is implemented. These consist out of the power plant itself, the wiring and the safety components. Furthermore, when it is a diesel generator set the fuel need to be paid. When the system gets older maintenances and service on the components must be done.

These costs can be covered differently. There are some projects which are subsidised by the government or other organizations. Also, a connection fee can be implemented to get the money from the people. With regular payments, the recurring costs should be covered. The question here is: How much can and should the user pay for electricity?

This question can be answered by taking a look at their current expenses for energy like kerosene and candles for lighting and batteries for using radios and watching TV. If the energy cannot be supplied on a few days, the people would need to buy kerosene to overcome these days.

Also, it is possible by researching for other villages which are similar to the village in which the system is implemented. Here it is necessary to consider how much they pay and consume.

Many households do not have a steady income and so it could be sometimes difficult for them to pay for the costs of the electricity.

It is necessary to calculate the costs which occur with the new energy source and also to compare it with the old one, if it pay off for the user or if it is much more expensive. Of course, it cannot be compared one by one because with an electrification much more comfort is given. Also, the people safe time because they do not have to recharge their batteries and buy kerosene and candles. As a result of this it is possible that the people are willed to pay more for this comfort.

Normally each family has to buy kerosene and batteries to cover their needs This self-provision would change, so that another person or company is responsible for supplying the electricity. First, it is possible that a private entrepreneur installs the mini-grid and so he will have all the responsibility and the risks like the financial, implementational, operational and managerial. Here the users have the least risk. Every household would just pay the electricity supplier instead of the local store who sells the batteries and kerosene.
Second, the mini-grid could be owned by the village or a few people from the village, like a cooperative or a user group. Here the group must be well structured, unified and it would be good if this group has successfully worked on other projects. The whole work in the project must be split up between the responsible persons. It is necessary that the organization keep going so that the system can be operated in the whole lifespan. Furthermore, it is also possible that one person from the village takes the leadership for the project. This can be a person who has already got an important role in the village or a person who is very interested in the topic. (NRECA-International)

3.2 Electricity supply

There are many different options to supply energy to the users. It ranges from the conventional diesel generator set to the renewable energies like wind, solar and hydropower. Here it is important to locate the power supply near the village because of transmission losses.
If a grid extension in this area can be easily made, it is often the best and cheapest way to supply the village with energy. Each of them got its own advantages and disadvantages.
The option of the grid extension also has got advantages and drawbacks. Normally there is no power limitation for the supply and the users do not have to care about the functioning of the supply. Also, the price for the electricity is relatively low, but also the costs for the grid extension must be calculated. In some countries, there is a poor supply of energy and so the users are sometimes cut off the grid which leads to unsatisfied users. The consideration about grid extension has got different points which need to be proven. It must be proven if the high voltage line is sufficient near to the town. Furthermore, there will occur costs for transformers and wiring and it must be checked if the grid can take the additional load.
The diesel or gasoline generator set is a common solution. This technology is broadly available, it is easy to transport and to install and it is also a cheap investment. The disadvantages must not be unconsidered. It is necessary to be able to deliver the fuel to the village in every moment, so rain seasons, which occur in Afrika from December to March and political uncertainties, can make this hard. Actually, if there is no electricity supply in the village, the lighting is normally done by burning fuels in lamps so a part of the fuel supply is already given. Fuel costs can rise in a short time so there is a dependence on the market. If the generator set is not maintained frequently by professionals it can lead to expensive replacements. Of course, the pollution must not be neglected. Here especially noise, disposal of oil and gas emissions have to be considered.

Renewable energy sources benefit from utilizing a source which is free and has got low process costs. The common solutions are here hydro-, wind- and solar power. Here the cheapest one is hydropower because it can supply energy 24 hours a day in comparison to the other ones which are addicted to irradiation or wind. With this technology also other machines like sawmills and mills can be mechanically powered which has the advantage that they do not consume electricity.
It is a considerable option to use solar power, because it is available throughout the whole year. The transformed energy can be directly consumed by the user at daytime. But the main energy needs occur at night time which has the significant drawback that here no energy is produced. So, the energy must be stored in batteries which have most of the time the highest costs in the system. Furthermore, in seasons with less solar irradiation a backup system is necessary to cover the whole needs of the village. So, it must be considered for each case which energy source would be the most efficient one for the whole system.

In rural electrification projects, many mistakes occur because of inexperience of the people who are building it up, but there are also parts which work well. As a result of this inexperience these mini grids can have less lifetime, efficiency and can also be dangerous. The consumption of the users must be controlled, so that each of them can use the same amount of energy. If this is not done, some users will consume more than they are allowed to and so the whole system gets out of the equilibrium. As a result of this it may happen that the generator runs hot or burns out. It is possible to control the consumptions by using smaller fuses and properly sized circuit breakers.
The poles for the entire cabling seem to be most of the time a big problem. They are often just improvised and do not regard to the safety aspects. Trees or hardwood and bamboo posts are mostly used for that. But as time pass the trees die or the posts rot. It is a good thought to start with these posts to save money and afterward to replace them one after another, but this will not happen. This is because when people see that the system work like this they are questioning why they should invest money, time and work in it.
If the planning in the beginning is insufficient, this will cause problems in the execution of the project. The conductor size must ensure that the voltage drop moves in an appropriate range. When it is too small there will show up losses which could have been impeded. In some cases, it has been tried to run the generator with a higher voltage to cover the voltage drop over the distance. But this is not a good way because it will reduce the lifetime of the generator and will also be bad for the lighting in the near surrounding of the generator.
In rural areas, the user needs mostly consist out of lighting of the houses. For this reason, it is not absolutely necessary to supply the houses with 230 V because it is also sufficient to use 12 V lamps with direct current. In these cases, it is necessary to supply the energy with 230 V to reduce the whole losses and afterwards to transform the energy in DC low voltage. This can improve the safety of the system so that the people cannot hurt themselves and cable fires are prevented. It also has to be taken a look at the negative side of this option. The transformer/rectifier unit increases the complexity of the system significantly and when the

costs of these units should be low, the efficiency will also suffer. For this reason, when the efficiency is low, much losses arise, which can be a significant amount of the produced energy in such mini grids.

As mentioned before, most of the time the costs have got a significant role in such projects and so the capital costs and the life-cycle costs should be minimized. If the capital costs are low, but afterwards the life-cycle costs are certainly high it would have been better to invest more in the project in the beginning. This should be preferred instead of the need to repair the system every now and then.

Furthermore, the user needs have got an important role in the project. These needs are mainly the lighting of the houses and entertainment. In the sector of the lighting, much energy can be saved by using a little bit more expensive and newer technology. This technology will last longer and consumes less energy. Here different types of lamps can be used. We distinguish between incandescent, fluorescent compact fluorescent and LED lamps. The LED lamps have got the highest lifetime and need also less energy to supply the same amount of brightness, so they should be preferred used. In comparison, the incandescent lamp has got the least lifetime and the least costs. Also, the use of the fluorescent can be a cheap option. The LED lamps are already taking over the market of lighting and so the price is dropping consecutively.

Another big use of energy occurs because of entertainment like radio, TV and cassette players/recorders. This energy is normally supplied by automobile batteries from which the energy is much more expensive than from a minigrid or the national grid. These batteries can be recharged in the nearest town and so there appear the costs of the transportation, charging and amortization. In relation to this the price per kWh is about 2 to 3 $. In comparison to the national grid which is about 0,10$/kWh and the mini-grid with a diesel generator set which is about 0,40$/kWh the price is quite high. Of course, in the minigrid the price can vary because of a large number of factors. A few different approaches are possible to solve the problem with the batteries.

- First it is possible to purchase equipment which can be used with AC and also DC from the batteries. For this option, an AC/DC converter would be necessary, which is normally included when purchasing a product like this. So, it would be just necessary to use the batteries when the people are outside from home.
- It is also possible to use the batteries further and to reload the batteries at home with a battery charger. This has got the advantage that the people could also supply energy when the grid does not work over a period of time.

Another source of energy consumption could also be motor based equipment like refrigerator, water pumps or wood- and metalworking equipment. These loads are significantly higher than the loads for lighting. So, if these equipment is introduced it need to be considered in the beginning of the project. It must be considered that the running current for these equipment is constant but to start the motors they need a much higher current which need to be supplied from the minigrid.

Furthermore, heat generating appliances can consume easily 1000 W or more and so they would be the biggest energy consumers in the system. It depends on the capacity of the minigrid but if it is not sufficient, the use of these appliances need to be permitted. For this reason, the generated energy would need to be risen significantly to meet these needs which can make the minigrid unattractive for the users because of rising costs.

The assessment of the demand is an important step in the whole project. Therefore, it is necessary to get an overview of the user needs and the additional needs which emerge in the following years. With this knowledge, it should be possible to size the generating powerplant and the conductors. It is necessary to size the system properly, so that the users are satisfied but also do not have to pay a high amount of money which is beyond their abilities. To make load projections which are realistic is often quite hard to do, because the users have little experience with electricity and so they will not be a great help. Furthermore, it is essential to be able to give the users a unit cost of electricity in $/kWh. This analysis can be made by researching for already electrified regions which are similar to this region, so that these can be compared. Different factors have got a role in these calculations. It is requisite to get an overview over the amount of disposal income, presence of local produced products and the access to the outside markets. Another important factor is the expected lifespan and if the user needs can change drastically over the years. Summarizing it can be said that before a real-life project can start, there are many different unanswered questions. Like mentioned in "Elements of electrification" these three points must be solved at first, to be able to continue with the project. In this sector experience has got a great importance. The cost of a project and the user needs are connected to each other and so in the beginning a cost has to be set to initiate the project.

The project must be treated step by step to ensure that it works well. First of all, there should be a meeting, with some people of the village and also the executing people, to determine the energy needs and the costs for the whole village. Then the tariff structure, the costs and the consumption need to be estimated to get an overview of the project. It is important to know the distribution system, where energy is needed and where to locate the poles. Furthermore, it need to be checked which line configuration, like for example single- or three-phase, will be chosen for the conductors. Afterwards, the costs and sizes for the conductors can be determined when the needs and the area to be supplied is known. If the costs for the conductors do not fit the supplied area, this area need to be changed to minimize the conductor size. Also, the poles have got an important role in the project and need to be located and designed carefully.

An important part are the user needs and which types of energy consumers are used. In this part, it also must be considered if the needs will increase or stay stable in the next years. When these points have been taken into account a proximately price per kWh have to be made for the users. It can be seen that the electrification of a village need much planning and so the main points of a project have to be defined to be successful in the following work. (NRECA-International)

4 Dimensioning of the system

The whole system is calculated with the program PVsyst. Therefore, a license was provided from the University of Valladolid. With this program, it is possible to dimension the whole system. There are different options of systems in the program, like grid connected or stand alone for example. This project will be looked at as it is grid connected in the first part, because the batteries with the charge controller will maintain the grid and so the inverter do not have to build up the grid and produce the frequency on its own. With this option, it is not possible to implement the batteries directly in the program. To get a better look at the charging and discharging process data will be extracted out of the program into an excel file to work with it.

First of all, it is necessary to select the right irradiation and climate data from the software. The location is Chifunda in Zambia and the data for this region is not available from MeteoNorm 7.1, which is considered to be the most reliable source for monthly meteorological data. For this reason, the data was needed to be imported from PVGIS which will provide all the global irradiation and diffuse irradiation. Furthermore, the wind velocity and the average temperature was available on the NASA-SSE site. In Figure 7 the whole global and diffuse irradiation, temperature and wind velocity is imaged from the imported data like mentioned before. As we can see here the solar irradiation is quite small in the rain season which have been analysed in "Climate, weather".

	Global Irrad. kWh/m².mth	Diffuse kWh/m².mth	Temper. °C	Wind Vel. m/s
January	174.2	78.4	22.2	2.14
February	164.1	68.9	22.2	1.95
March	196.8	80.7	21.9	2.18
April	180.6	52.4	21.5	2.59
May	179.2	41.2	20.8	2.75
June	162.6	37.4	19.2	2.99
July	168.6	40.5	19.5	3.24
August	191.6	44.1	21.9	3.71
September	209.7	46.1	25.2	4.02
October	226.9	61.3	26.6	3.93
November	202.2	60.7	25.6	3.26
December	187.5	73.1	23.2	2.36
Year	**2244.0**	**684.8**	**22.5**	**2.9**

Figure 7 MeteoNorm data (own figure)

4.1 PV panel orientation

Moreover, it is necessary to determine the tilt of the PV panel and also the azimuth angle, because this location is in the south of the equator the panels have to face to the north for the optimal results. There have been a few options tested and compared to get to the optimum of the orientation. Also, the summer and winter time is the opposite of the time in Europe, so from October till March is summertime and from April till September is wintertime.

As in Figure 7 can be seen the irradiation in August and September is quite high in comparison to the one in January and February. This is because of the rain seasons in January and February. First the simulation was taken with 30° tilt and an azimuth angle of 60° but this was not a sufficient solution for the panels.
It was also taken into account to organize the panels in an east and west orientation which can be seen in Figure 8, to save space, but because there is no lack of space in this area it is not the optimum for the orientation of the panels.

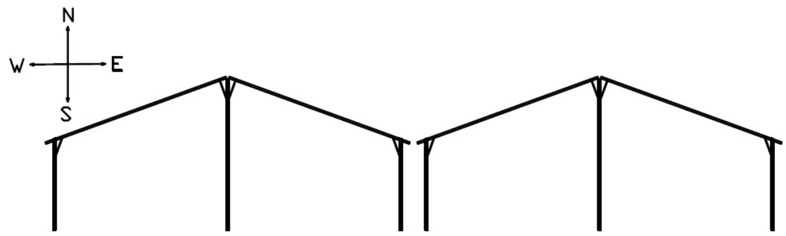

Figure 8 east west orientation (own figure)

When the orientation is set with lower plane tilt there will be more energy harvested in summer and the contrary in winter.
The azimuth angle is for both summer and winter best when it is 0° because otherwise the panels will be shaded at a certain time.
With the help of a shading simulation which will be explained later it was possible to consider the orientation with 20° tilt and a 0° azimuth angle. For this tilt, the auto purification was reconsidered and it will be sufficient. The auto purification is important for the cleaning of the panels. Therefore, when the rain hits the PV panel it should wash away most of the dirt and particles. To assure this it is necessary to have the panels tilted at least 15°. (Solar World AG, 2009)
The orientation and tilt of the panels can be seen in Figure 9.

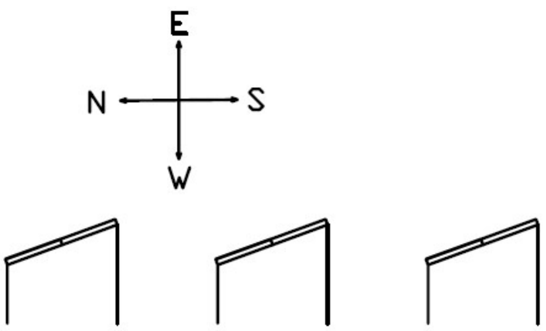

Figure 9 Orientation and tilt of the panels (own figure)

In Figure 10, Figure 11 and Figure 12 can be seen how this tilt and azimuth angle affects the global irradiation which gets to the collector plane and so how much is lost. “The transposition factor is the ratio of the incident irradiation (GlobInc) on the plane, to the horizontal irradiation (GlobHor). I.e. what you gain (or loose) when tilting the collector plane.” (PVsyst-transposition_factor) Figure 12 shows that this configuration is the absolute optimum for the whole year of the system. If the angle would be reduced to optimize the gained energy in summer, it may not be sufficient for the auto purification effect. It also makes less sense because of the rain season in summer.

Figure 10 winter meteo yield (own figure)

Plane tilt: 20°
Azimuth angle: 0°

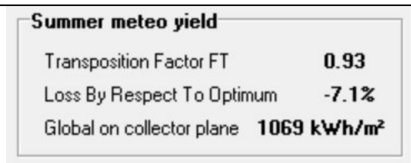

Figure 11 summer meteo yield (own figure)

Plane tilt: 20°
Azimuth angle: 0°

Figure 12 yearly meteo yield (own figure)

Plane tilt: 20°
Azimuth angle: 0°

4.2 Batteries

There are different types of batteries available on the market. First of all, the most common one is the lead acid battery. This battery type has normally got a lifespan of about 10 years. It is only possible to discharge the batteries to a certain value which is common to be 30 or 40% of the capacity. Most of the time these batteries are not maintenance free.
The other type of battery is the Lithium Ion battery. With this type, a lifespan of about 15 to 20 years is promised by the manufacturer and they can be discharged to 10% of the capacity. Furthermore, this type of battery is maintenance free but they are also more expensive.
In this project, it was very important to have a long battery lifetime and also to be able to have much charge and discharge circles. Additionally, it was necessary to have a maintenance free battery in this location because there are no technicians available in this town.

So, the used batteries are lithium ion batteries from the company ABB. This company offers a package in which the whole batteries and charge controllers are introduced. They also have the task to arrange the grid together. This facilitates the whole process of installation for the system and also the company will be responsible for this part of the project. One package has got 83 kWh and there will be different thoughts about how many will be needed for the system. Furthermore, the charge controller will be needed to charge and discharge the batteries. In this package, they are included and will be able to manage a load of 60 kW.

4.3 Backup system

The backup system will be a diesel generator system and is predefined by the company with 40 kW. It will be used to cover the energy needs which cannot be supplied by the PV system. It is necessary that the PV system is dimensioned to reduce the running hours of the backup system drastically, so that the PV panels supply the most energy. Sometimes over the day when the user needs peak, the backup generator has to run a few hours before this time, to load the batteries. So, to be able to supply 24 hours a day the energy which is needed.

4.4 User needs

The user needs are one of the most important parts in a PV system. These needs have to be covered by the energy supplying systems, so in this case it is the PV system together with the storage system and the backup system. In Table 1 the whole user needs are shown. In the village, there is a mill to grind the cereals which will be active from 7:00 to 17:00. Of course, a refrigeration is needed, it is not stated where the refrigerators are, if the people share a few ones, or if they are otherwise used. Schools start at 8:00 and end at 16:00 but have a quite low energy consumption which is just due to lighting, overhead projectors and so on. The shops and hospitals are very important and so they have to be preferentially provided with energy. Nearly half of the whole energy consumption is due to the households. There is a small peak in consumption in the morning at 7:00 till 8:00 and the biggest peak occur from 20:00 to 22:00. At this time, all the users need which are lighting at home and also the TV´s will be switched on in many households. These times are critical for the PV system because in the morning the panels cannot produce the full energy and at night time they do not produce any energy at all. So, these peaks need to be partly or fully covered by the battery system, or the backup system. In relation to this there have been thoughts about how the energy consumption can be reduced or what the PV system is able to supply.
As shown in Table 1 the reductions are about 60% of the whole energy consumption.
There will be two trials with different PV sizes. In the first option the focus will be on covering the reduced energy needs and in the second version, the focus will be on covering nearly the whole energy needs. The user needs are graphically shown in Figure 13.

Hora	Consumption segmentation (kW)					Total con-sumption (kW)	Total con-sumption with reductions (kW)
	Mill	Refrigeration	School	Shops, hospital	House holds		
00:00		5		2	3	**10**	**5**
01:00		5		2	3	**10**	**5**
02:00		5		2	3	**10**	**5**
03:00		5		2	3	**10**	**5**
04:00		5		2	3	**10**	**5**
05:00		5		2	3	**10**	**5**
06:00		5		2	3	**10**	**5**
07:00	15	5		3	30	**53**	**15**
08:00	15	5	2	10	10	**42**	**20**
09:00	15	5	2	10	5	**37**	**20**
10:00	15	5	2	10	5	**37**	**20**
11:00	15	5	2	10	10	**42**	**20**
12:00	15	5	2	10	10	**42**	**20**
13:00	15	5	2	10	10	**42**	**20**
14:00	15	5	2	10	10	**42**	**20**
15:00	15	5	2	10	5	**37**	**20**
16:00	15	5	2	10	5	**37**	**15**
17:00	15	5		5	5	**30**	**20**
18:00		5		5	20	**30**	**30**
19:00		5		5	28	**38**	**40**
20:00		5		5	68	**78**	**60**
21:00		5		3	68	**76**	**50**
22:00		5		3	8	**16**	**15**
23:00		5		3	3	**11**	**5**
					321	**760**	**445**

Table 1 User needs (own table)

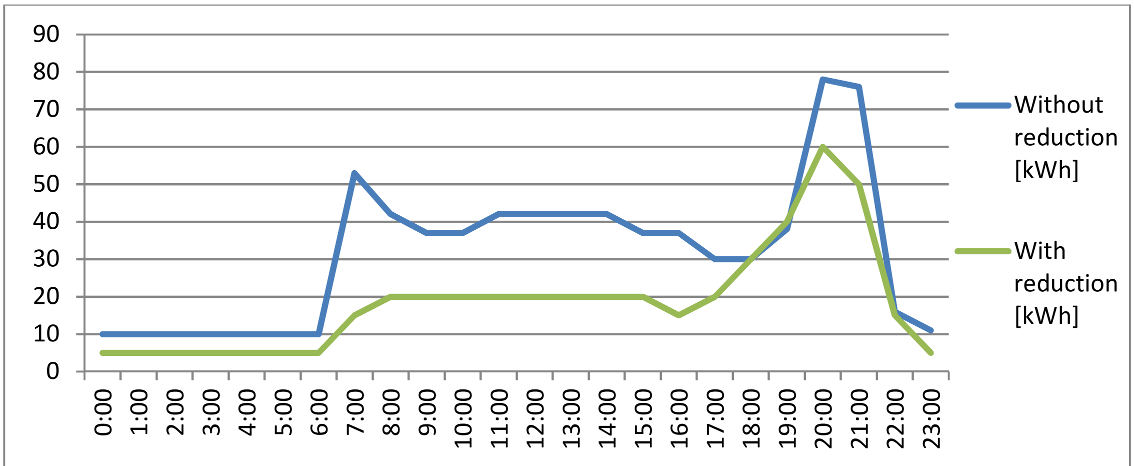

Figure 13 User needs (own figure)

4.5 First option

Like mentioned before here the emphasise is to cover the reduced user needs, and therefore different sizing of the system has been tried.

4.5.1 Selection of the components

All the inverters and the photovoltaic panels are predefined by the company.
It is important that the components which are sensitive against rain need to be in a dry room, this is especially for the battery system. The inverters will be protected with a high IP standard so they can be outside. Also, an important point will be that the connection boxes and the cases for the electrical components are waterproof.
The inverters will be from Fronius, which is an Austrian company which is working in the photovoltaic sector since 1992 and it has specialised on inverters and has got a good experience in this field.
There will be three inverters of FRONIUS ECO 27.0-3-S used, with a nominal output power of 27 kW so the global inverter power amounts 81 kW.
The photovoltaic panels TSM-315 PD14 from Trina Solar will be used for this project. This panel is often used for large scale photovoltaic power plants. The maximum power of this system is set to 90 kWp to meet the reduced energy consumption. So, with a safety factor of 10% because the panels are tested at standard test conditions at 1000W/m² and 25°C and they will not reach 90kWp the power will be 99 kWp for the whole system. The inverters can handle this power because the standard test conditions will not appear in real conditions.
In the datasheet of the inverter, we can see that the operating voltage is from 580-850 V and the maximum input voltage is 1000 V. Because of this, the voltage of the PV panels should be in the range of 580 to 850 V and the open circuit voltage at -10°C should be smaller than 1000 V. The open circuit voltage of the TSM-315 PD14 panels is 31,6V at the maximum power point at 60°C and 50,8 V at -10°C. In relation to this, with 19 panels in series it is possibility to operate the system. With this number of panels the voltage at the maximum power point at 60°C is 600V and the open circuit voltage at -10°C is 966 V. This low temperature will never be reached in this region and so also 20 panels in series would be possible. Here the open circuit voltage at -10°C would be slightly over 1000V. So, both values are in a good range. It is not possible to use 18 modules because then the voltage at the maximum power point at 60°C would be lower than 580 V.
So now by varying the number of strings we can increase or decrease the output power.
The first attempt was with, 15 strings and 19 modules in series to meet the goal of Pnom ratio of 1,1 and to reduce the overload losses of the inverter.

The Pnom ratio is the normalized performance index. It was introduced to facilitate the comparison between different PV installations and is now fixed in IEC EN 61724 norm. The

Pnom ratio is defined as the output AC power and the PnomDC = PnomAC / Efficiency. (PVsyst-Inverter-Array-sizing)

With 15 strings and 19 modules, the Pnom ratio is 1,11 and there will be nearly 0% overload losses which will be about 15,1 kWh. But with these conditions the panels can only provide 90kWp which will be even less because of the before mentioned standard test conditions. At 1000W/m² and 50°C it would be just 80,6 kW which will not be sufficient for the supply of the village.
As a result of this, to meet the operation conditions of the inverter, it was decided to take 19 modules in series with 17 strings, which has risen the nominal power of the whole system to 102 kWp and to 91,4 kW at 1000W/m² at 50°C. With these conditions, the inverters are slightly undersized but because the photovoltaic panels are tested with the standard test conditions, it will be sufficient for the system. Furthermore, the maximum PV power for this inverter is 35,7 kW so for three inverters it is 107,1 kW which is higher than 102 kW. The disadvantage here is that an overload loss of the inverter of 1,7% occurs which results in a loss of about 3952 kWh and that the Pnom ratio is 1,26 but it should be around 1,1.
For the arrays, the Pnom ratio is defined for the STC so in our case it is 102 kWp. So, the whole Pnom ratio is Pnom array / Pnom inverter = 1,26. But it will be lower because of the STC and not all the losses are introduced in this program into that factor.

4.5.2 Connection of the panels

There have been different thoughts about how the panels should be connected and where the inverters should be placed. Like in Figure 14 can be seen the inverters and the protection systems will be in the left front corner of the panels which are facing to the north. But there need to be a distance to the panels because of shades. It cannot be placed in the back of the panels because the village is located in the north of the system. The inverters, do not need any protection against the weather because they have got an IP 66 standard. The first number gives information about the protection against the intrusion of dust. Six is the highest protection which means that dust cannot intrude into the inverters. Furthermore, the second number gives information about the intrusion of water. Here the six stands for the protection against strong water beams. So, the inverters are enough protected to be mounted in the rain. For the fuses and protections, it will be necessary to protect them against entering of water.

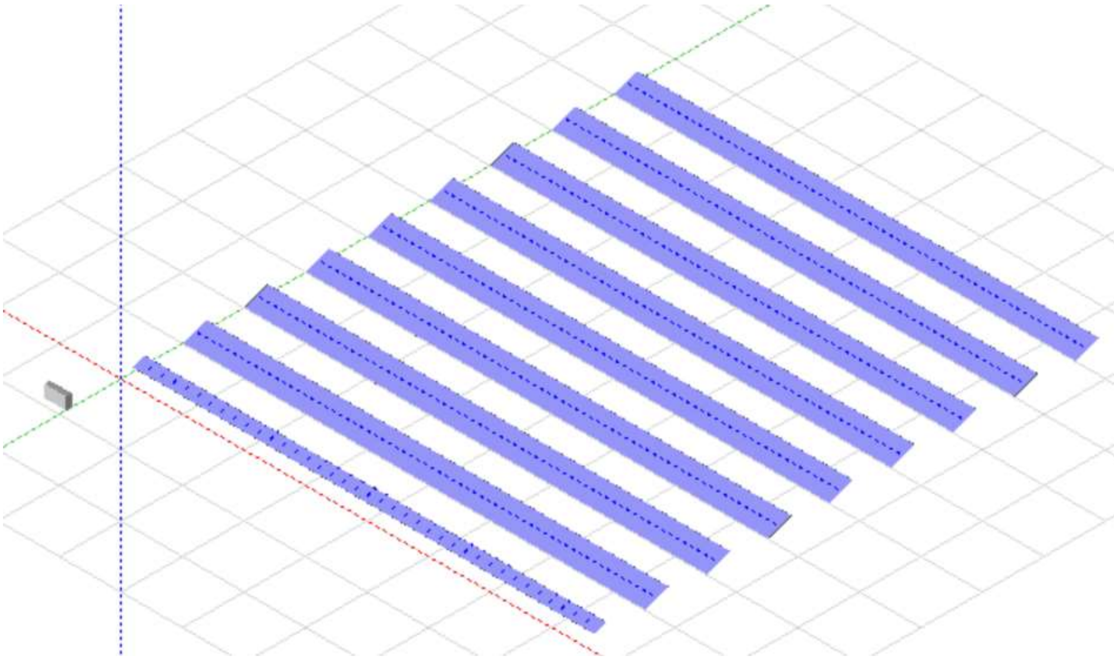

Figure 14 PV panels arrangement second attempt (own figure)

There are different options to connect the different strings with the inverters. In Figure 14 can be seen that there are 9 rows of PV panels and that the 1st row just has got 1 string.

1. First, it is possible that each 5 strings can be connected in a box at the left side of the 3rd, 6th and 9th raw. So, the cable size is smaller to the boxes and from there the size will be implemented bigger. This option has the advantage that only six wires are connected to the inverters.
2. Second, the panels can also be directly connected with the inputs of the inverters. This has the advantage that the size of the cables does not have to be variated, but the disadvantage is that the length of the cables will be higher. Because of the losses, the cables should be of a size where the losses are in an acceptable range.
3. Another option is to connect only two strings in one box which has the advantage that the wiring length to the boxes can be minimized and so also the used copper mass and the losses which appear. In this variation one box is fixed in each raw so that the minimum cable length is required. The only PV string will be connected directly to the inverters.

Now that the different options have been shown the different cable sizes and lengths were calculated in excel. Afterwards PVsyst was used to calculate the copper mass and the loss fraction. Here it was possible to introduce different diameters to get the best and most sustainable way to connect the panels.

4.5.3 Wiring

In Figure 15 the different options are introduced and the whole lengths of the cables and the ideal settings for each variant are taken into account. With an analysis of these options, the best has been chosen.

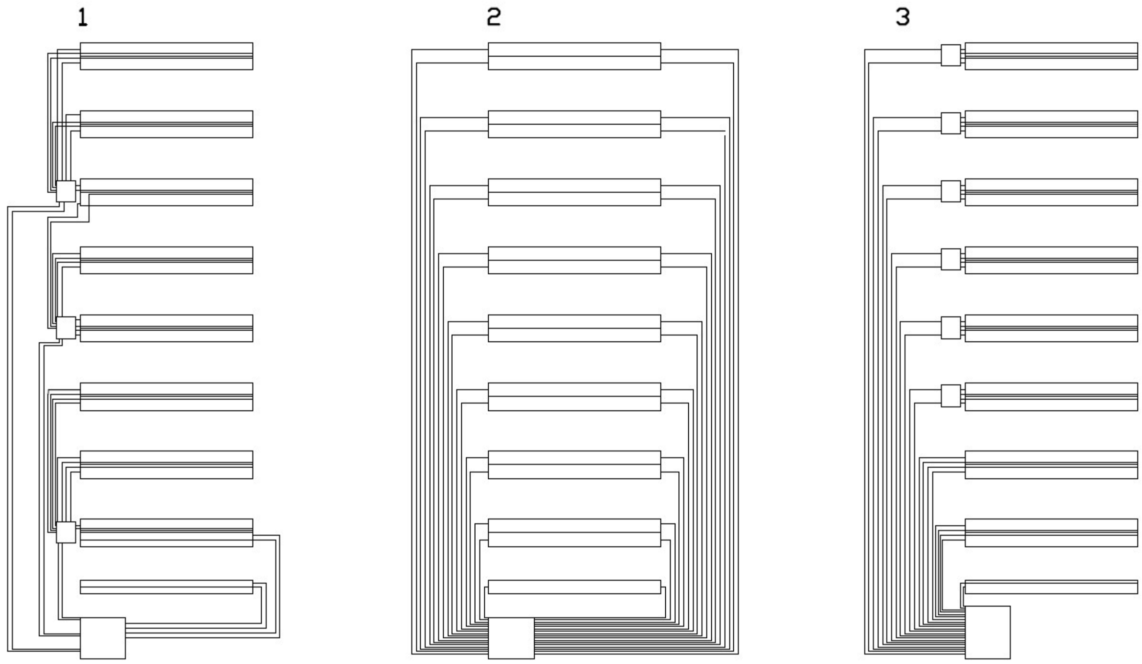

Figure 15 wiring options (own figure)

1. For the first variant, we have got 3 boxes which are located at the left side of the whole system. There the whole cables of each 5 strings are connected together to wire it to each inverter. The cables will be wired on the ground so two cables, one for the positive and one for the negative side of the panel, will be connected to the box. So, to get the length from the panels to the ground 5 strings are multiplicated with 0,5 meters and with 2 because of the two cables. The length of the strings are 38 meters and for each box we have got 5 strings to connect, so these two numbers multiplicated results in the length of the negative cable for one box. The box is located in the 3rd row so the distance to the two rows are 5 meters and 10 meters. So, each row has got 2 strings with four cables which must be multiplicated with the distance. As a result of this, a length of the cables of 255 meters is calculated. For the second box, there is only one string 10 meters away and so the length of the cables is 235 meters. The third box is similar to the first.

   Here the two nearest strings to the inverters are connected without a box. This length accounts to 182 meters. Afterwards, 2% as auxiliary are added and so the final length accounts to 946 meters with 16mm². From the box to the inverter a 70mm² cable will be used and the distances are 34,5, 19,5 and 4,5 meters from the boxes. These values must be multiplicated with 2, because we have two cables. Here are 5% auxiliary added because it is a much shorter distance than the other which results in 144 meters. This results in a copper mass of 1869 kg and a loss fraction of 1,5% which refers to the loss of voltage over the whole distance.

2. Each inverter has got 6 inputs, so it is possible to wire each string to one input and there will be two strings which are connected to all inverters. There are 5 meters between each panel row with two strings and there are 8 rows. So, the largest distance to the inverters are 40 meters plus 0,5 meters because of the height to the ground. Then this distance will be reduced in 5 meter steps for each row. For all panel rows, there are two strings and so all these lengths are summarized. Then they are multiplied by two because of the negative cable of each panel. Afterwards, the length from the right side of the panels to the inverters for each negative cable must be added. Each row has 38 meters and all in all there are 17 strings so it results in 646 meters of wiring. Summarized it results in 1383 meters and with 2% auxiliary in 1411 meters of 25 mm². The diameter of the cable must be so big to lower the loss fraction. In this case, the copper mass is 3021 kg which is significantly more than in the first one. Also, the loss fraction is more than in the first option and amounts to 2%.

3. As a third option, it will be assumed that each row has got a junction box, except the first one because it is just one string. So, the cables to the junction boxes can be of a 16mm² diameter cable and from the boxes it will be a 70 mm² cable to reduce the loss fraction. To each box are 4 cables of two strings connected, so it can be easily calculated. 4 times 0,5 meters for the height must be taken into account and also 2 times the length of the whole string which is 38 meters. This results in a length of 78 meters for each box and the length for the first string is the half and so 39 meters. Summarized it is 663 meters and with 2% auxiliary it results in 676 meters.
   From these boxes to the inverters the largest distance is 40 meters. Like in the second option the panel rows have got a distance of 5 meters to each other. So, this results in a length of 180 meters and with 2% auxiliary in 184 meters. Furthermore, for each box are 4,5 meters of cable added to take the distance to the inverter into account. This results in a copper mass of 1812 kg and a loss fraction of 1,4%.

As we can see in Table 2the first option is the best because it will need the least copper mass and also the loss fraction is 1,6% and so the lowest of all.

	from panels to box [m]	from box to inverter [m]	diameter [mm²]	Copper mass [kg]	Loss fraction [%]
variant 1	946	144	16 / 70	2263	1,6
variant 2	1411	-	25 / -	3021	2
variant 3	793	392	16 / 70	2345	1,8

Table 2 wiring options (own table)

First of all, there will be the least costs because of less copper mass. Furthermore, the wiring effort is minimized because less length of wires will be needed. Also, the loss fraction can be minimized to 1,6% by using a smaller cable size of 16 mm² to wire the panels to the boxes and then using a quite big size of 70mm² of wires to the inverters. Of course, there is also the option to use only 50mm² or 35mm² to lessen the wiring effort and to reduce copper mass, but then the loss fraction would be 1,7% for 50mm² or 1,8% for 35mm². This will depend on the maximum losses which are allowed to occur and also the losses which occur in the AC circuit. In Table 3 can be seen how the variant 1 can be changed to decrease the loss fraction.

	from panels to box [m]	from box to inverter [m]	diameter [mm²]	Copper mass [kg]	Loss fraction [%]
variant 1	946	144	16 / 120	2263	1,5
variant 1	946	144	25/70	3402	1,1

Table 3 variation of variant 1 (own table)

The diameter which is used within the string is calculated in the following calculation.

$$A_c = \frac{2 * l * I_{st}}{0{,}01 * U_{MPP} * n * k}$$

A_c… diameter of the string conductor
l=38m…. length of the string conductor
I_{st}=8,51A…. string current
0,01…. 1% voltage drop
U_{MPP}=37,1V … voltage in maximum power point
n=19… number of in series connected panels
k=56mΩ/mm²…. electrical conductivity of copper

The maximal diameter is 1,64 mm² and the next possible normed diameter would be 2,5mm². But it will be 4 mm² chosen to reduce the losses.

Each of the inverters is only equipped with one MPP Tracker and so the worst panel in the set of 5 strings in the whole system will define the current. In this wiring option where two strings are split between the three inverters, these strings should be one of the best. Each PV panel is different from another, so they also vary in performance. Some manufacturers who sell PV panels provide the option that they first test each PV panel with a flash test and then make sets of better panels and sets which are worse than the other ones. So, it should be taken care about which panels are connected in one string and then also which strings are connected in one inverter.

Also, the AC circuit from the inverter to the injection point must be examined. Till now there is no further information available how the supplying cables are wired through the village. There have been some ideas of how the energy supply to the batteries and the users can look like. This scheme can be seen in Figure 16. So, there will be some boxes in the village from where the energy is directly supplied to the users. In PVsyst it can be simulated when the distance to the battery pack is 500 meters how much the loss fraction at standard test conditions will be. It cannot be treated that exactly because the cables will be lead through the village and supply the energy to the houses and not only to the battery pack. But there have been different attempts to introduce this scope into the project. In the following calculations, it can be seen which size of cable will be needed for each inverter. This wiring size will also be the same for the second option, which will be explained later.

Calculation of the AC wire:

$$A_{AC} = \frac{P_{Inv} * L}{\kappa * \Delta v * U}$$

P_{Inv}… inverter power 27kW

L… cable length 500m

Δv… voltage drop 2 ≙ (1%)

U… voltage 400V

κ … Specific conductivity Aluminium 36 $\frac{m}{\Omega\, mm^2}$

$A_{AC} = 468{,}75\ mm^2$ for the whole wire.

$A_{AC} = 156{,}25\ mm^2$ for one phase.

The next bigger norm diameter is 185mm². For that reason, a 3+N cable is needed with 3x 185mm² and 1x 95 mm².

There is also the possibility to wire two cables for each inverter with 3x 120² and 1x 70 mm² like it can be seen in Figure 16.

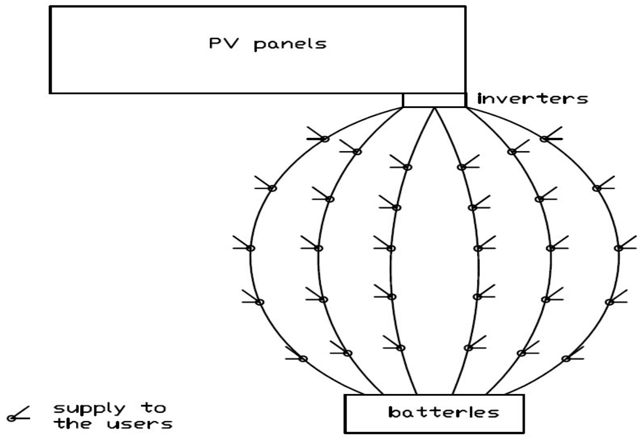

Figure 16 energy supply in the village (own figure)

4.5.4 Shadowing analysis

There are different options in PVsyst to implement the shading scene of the panels. First of all, shading objects can be introduced in the solar altitude diagram by simply implementing the height and the azimuth angle of the object in relation to the PV panel height. This gives a rough analysis of the shading scene to be able to assess the losses which occur because the panels are shaded. For PV panels, it is crucial to have the whole area of panels irradiated, because even if just a little part is shaded the PV panels can just produce a minimum amount of energy.

There is no possibility of visiting the area in which the system will be mounted so it is assumed that there are no shading objects in the proximity and so all shadings in the horizon are set to zero. Also on google earth it can be seen that in front of the PV panels only the airplane landing field is. Furthermore, this shading analysis is not as exactly as the near shading analysis. As it can be seen in “Connection of the panels” the whole shading scene has been introduced to the program. There are eight rows with two strings and one raw with one string, so there are seventeen strings with nineteen panels in series. The whole panels will be mounted with a pole mounting system with an N profile which will be explained in “Mounting system”.

To minimize the area of the whole system the panels have been mounted horizontally on the construction. This step will maximize the area in the horizontal length but it will minimize the vertical length. Each two strings will be mounted one above the other in the horizontal direction to get the best non-shading results. So, it occurs that the strings can be mounted much nearer to each other, because the shade of the panels in the front do not have a big shadow which falls on the panels in the back. In the near shading analysis of the program, the panels are organized as they will be in the real scene then. To construct this scene the panels, have a 20° tilt and are aligned to the north. Moreover, the distance between each mounting structure are five meters. There have been different options simulated to get the ideal distance. The program is able to make a simulation for every day of the year, of the sun height and as a result of this, also of the shading scene. In summertime, the panels in the back are not shaded at any time from the panels in the front. At wintertime, the panels are just shaded at 20 minutes in the morning and in the evening which occurs because of the low solar altitude. This just leads to minimal losses which can be accepted.

It was also necessary to introduce the module layout into the program. This was necessary so that the program knows how the panels are connected and how the strings are organized. As a result, the calculations are done correctly. In Figure 17 can be seen how the different strings are organized and which panels are connected in series. There is an amount of 323 panels and each colour represents one string in the whole system.

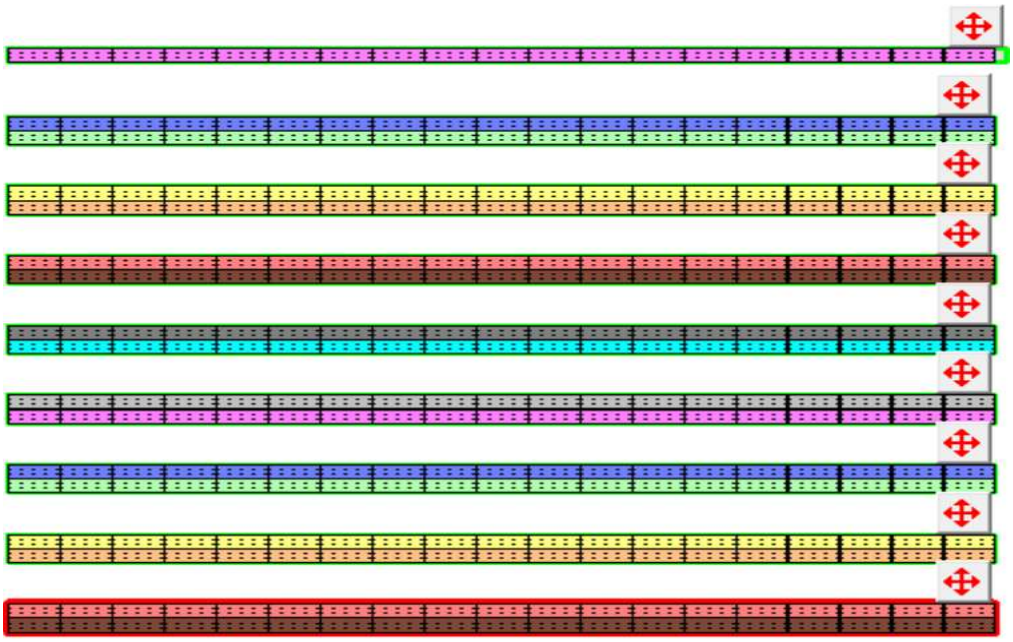

Figure 17 module layout (own figure)

4.5.5 Summarization of the first option

In this option 4 battery packs with each of 83 kWh has been used, which resulted in a total amount of 332 kWh. As it can be seen in Table 4 nearly the whole reduced energy needs are covered. It is more energy produced than the reduced energy loads are. This is because the produced energy is 172,74 kW and the needed energy is 162,43 kW, so even more than 6 % are produced more than needed. We can also see in Table 4 that four batteries will not make sense for the needs without reduction because more energy from the panels would be needed and cannot be stored in the battery pack. This can also be compared with Figure 18 which can be seen in the “Second option”. Here it can be seen that it is only useful for the whole energy consumption to rise the battery size to 2 units. With this option, the aim to supply nearly the whole reduced energy needs was fulfilled and now it was the task in the next chapter to supply nearly the whole energy needs without reduction.

The charge controllers will be sufficient for the charge process because the maximal charged power will be 55 kW. For the discharging process, it will be slightly undersized because 62 kW are maximal discharged of the battery. It is not useful to introduce a second charge controller, because there are just 2 kW difference. Therefore, the backup generator has to work a few hours more at some days.

RESULTS										
With Reduction										
	E_Grid	E User	E Panels	E Load	SOC Bat	Discharge Bat	Charge Bat	Load ext		Lost energy
Total	104,69 MWh	68,05 MWh	172,74 MWh	162,43 MWh	46,02% Average	83,35 MWh	83,37 MWh	14,29 MWh	0,98 h/day	17,13 MWh
Ratio /E Load	64,45%	41,90%	106,35%	-----	-----	51,32%	51,33%	8,80%		10,54%
	106,35%								-1,75%	

Table 4 results of first option (own table)

4.6 Excel program description

Like mentioned before it is not possible to implement the analysis of the battery charge and discharge process in PVsyst. Therefore, the energy which is supplied to the user, the energy which is supplied to the “grid” and so to the battery and also the user needs had to be extracted from PVsyst into an Excel file and there it was possible to start the analysis. This is easily possible with the software and so, the data for every different option can be simulated. The software is able to provide data for every hour in every day of the year.

The initial point for the user is to be able to introduce the necessary data into the program. In Table 5 the different parameters which will be set by the user are introduced.

INPUTS												
Battery		Battery total		minimum battery load		Factor need	Factor losses	Factor charge	Factor discharge	Factor panels	beginning SOC battery	
83	5	415000	415	10	41500	1,00	1,00	0,96	1,04	1,00	25,00%	103750,00
kWh	**units**	Wh	KWh	%	Wh							

Table 5 input values for the calculation (own figure)

The whole factors will be listed in the following list but they will be described in the section below.

- First the size of the battery and the units must be defined.
  With these two values multiplicated we get the electrical energy, once in Wh and also in kWh.
- The minimum battery load which is possible without damaging the battery, can be introduced in percent and the program will calculate it in Wh.
- The need factor is set here to 1, so the user needs are as big as introduced in PVsyst.
- For the loss factor applies the same as for the need factor.
- The charge factor is 0,96 and the discharge factor is 1,04.
- The panel factor gives us a rough tool to increase the panel size easily.
- Also, the actual state of charge of the battery is introduced.
- Finally, the power of the backup generator must be defined.

There have been different factors introduced into the excel program to be able to easily change the different values without changing the data in PVsyst and afterwards to export it one more time.

For the load which is needed from the users, the need factor was introduced to get an insight how it would affect the charging process of the battery. If the needed load is equal to the stated load this factor will be 1. So, if this value is increased the needed load from the user will also be risen. For example, when the factor is 1,2 the user needs are risen by 20% in each hour.

To increase or decrease the losses of the energy which are produced by the panels a loss factor was made. If the losses are equal as before this value will be 1 and if they should be increased a value a bit higher than 1 will be chosen.

When the battery is charged, or discharged, energy is getting lost because of losses in the transformation. As a result of this further two factors, one for the charge and one for the discharge process were introduced. When the battery is discharged less energy can be effectively used than which is taken from the battery. In relation to this, the discharge factor is slightly higher than 1. Usually the energy which is lost at the charge- and discharge process is equal. It depends on the charge regulator of the battery. There is no datasheet of the charge regulator available by now. So, it will be fixed to a value of 4% at discharging and charging and because of this the value is 1,04. The charge factor is slightly lower than 1, because less energy will be supplied to the batteries than the panels produce. Like mentioned before the losses are here also set to 4% and so this factor is 0,96. These factors can be varied depending on if the transformation losses are higher or lower.

In Table 6 the imported data from PVsyst can be seen, which are the first two rows and the last row. This data is the energy which is injected into the “grid” (battery) and the energy which is supplied to the user. This two loads added are the whole energy which the panels provide. Furthermore, we can see the user needs on the right side of the table, which are in this case the reduced loads.
This energy was multiplicated with a panel factor to be able to simulate a variation in the size of the panels, this factor will be 1 if it should be as stated as in the first trial in PVsyst with 102kWp. It is not very exactly because if the panel size is increased there will be more losses and different conditions, but to get an overview how it can be implemented it is useful. This tool will be necessary for implementing the second option where the size of the panels and the batteries for covering nearly the whole energy needs are calculated. In Table 6 it can be seen how the energy injected into the battery is variating in the fourth column with the factor. Here for example the panel factor is set to 1,2 which means about 124 kWp.

date	E_Grid	E User	E Panels	E_Grid	E User	E Panels	E Load
	W	W	W	W	W	W	W
	without factor	without factor	without factor	with factor	with factor	with factor	
01,01,2017 00	0,00	0,00	0,00	0,00	0,00	0,00	5000,00
01,01,2017 01	0,00	0,00	0,00	0,00	0,00	0,00	5000,00
01,01,2017 02	0,00	0,00	0,00	0,00	0,00	0,00	5000,00
01,01,2017 03	0,00	0,00	0,00	0,00	0,00	0,00	5000,00
01,01,2017 04	0,00	0,00	0,00	0,00	0,00	0,00	5000,00
01,01,2017 05	0,00	0,00	0,00	0,00	0,00	0,00	5000,00
01,01,2017 06	2792,50	5000,00	7792,50	4351,00	5000,00	9351,00	5000,00
01,01,2017 07	8071,70	15000,00	23071,70	12686,04	15000,00	27686,04	15000,00
01,01,2017 08	19085,00	20000,00	39085,00	26902,00	20000,00	46902,00	20000,00
01,01,2017 09	31436,00	20000,00	51436,00	41723,20	20000,00	61723,20	20000,00
01,01,2017 10	39040,00	20000,00	59040,00	50848,00	20000,00	70848,00	20000,00
01,01,2017 11	42200,00	20000,00	62200,00	54640,00	20000,00	74640,00	20000,00
01,01,2017 12	41413,00	20000,00	61413,00	53695,60	20000,00	73695,60	20000,00
01,01,2017 13	36627,00	20000,00	56627,00	47952,40	20000,00	67952,40	20000,00
01,01,2017 14	27841,00	20000,00	47841,00	37409,20	20000,00	57409,20	20000,00

Table 6 imported data (own figure)

Furthermore, the state of charge of the battery is the main part of the whole program, so we will get into detail here.
There are different cases, which have to be taken into account because they will occur when the battery has different states of charge. In these calculations, the energy from the panels need to be multiplicated with the loss factor, because this factor, as earlier mentioned, will be used to increase or reduce the losses which occur in the whole system. So more, or less energy can be supplied to the user and the batteries. Then the user needs multiplicated with the need factor, which can increase or decrease the whole needs, will be subtracted.
This value will be called <u>battery value</u> from now on and is important to know, because it shows if the battery will be charged or discharged, or if the energy need to come from the backup system.

The different states of charge of the battery will be analysed in the following text. It is important that the battery must not be discharged more than a specific percentage of the whole load, which is given by the manufacturer. Furthermore, in the following cases, the different processes like charging, discharging and holding the maximum charge are analysed.

1. Remaining the minimum amount of load of the battery
   When the battery value multiplied with the discharge factor plus the state of charge from the hour before, is smaller than the minimum load of the battery, the minimum load of the battery will be in this cell and the energy must be supplied from the backup system. Here the discharge value is taken because the load which is needed from the user is higher than the energy which the panels can supply. In this case, nothing is happening with the battery because it has got too less energy.
   Here the text is written like a function:
   (Battery value x discharge factor + state of charge from hour before) < minimum load of the battery → new value = minimum load of the battery
2. Charging process
   If the battery value multiplied with the charge factor, plus the state of charge from the hour before, is smaller than the energy from the full charged battery AND the energy from the panels multiplied with the loss factor is greater or equal the energy which is needed from the user multiplied with the factor for the need → then the battery value multiplicated with the charge factor plus the state of charge from the hour before will be the new value for the state of charge.
   So, the battery will be loaded in this case.

   (Battery value x charge factor + state of charge from hour before) < energy from full charged battery AND energy from panels x loss factor >= needed energy from the user → new value = battery value x charge factor + state of charge from hour before

3. Discharging process

   When the battery value multiplied with the charge factor plus the state of charge from the hour before is smaller than the energy from the full charged battery AND the energy from the panels multiplied with the losses factor is smaller than the energy which is needed from the user multiplied with the factor for the need, the battery value multiplicated with the discharge factor plus the state of charge from the hour before will be the new value for the state of charge.

   This case shows how the battery reacts when it is discharged.

   (Battery value x charge factor + state of charge from hour before) < energy from the full charged battery AND energy from the panels x loss factor < needed energy from the user → new value = battery value x discharge factor + state of charge from hour before

4. Battery is maximal charged

   If the battery value multiplied with the charge value plus the state of charge from the hour before is bigger than the energy from the full charged battery.

   The full charged battery will remain loaded.

   (Battery value x charge factor + state of charge from hour before) > energy from the full charged battery → new value = full charged battery value

As we can see in Table 7 these four cases are applied. Also, the state of charge is outlined in percent in the cell next to the state of charge of the battery.

When the battery is discharged, there will be a need of energy. This need from the battery will be calculated and multiplicated with the discharge factor. Afterwards this amount of energy is subtracted from the state of charge from the hour before. The same occurs for the charging of the battery but vice versa and with the use of the charge factor.

When the battery has reached the minimum load, which is possible for it without damage the energy must come from another source. If the battery was not on the limit of discharge in the hour before, this energy will be supplied to the users and the rest have to be supplied from another source.

The lost energy is the energy which is lost when the battery is full and the user needs are covered. To use this excess of energy the user needs can be risen in these particular hours. In the example of Table 7 there will be no lost energy, because all the produced energy is needed.

E Load	Load Bat	Load Bat	Discharge Bat	Charge Bat	Load ext	Lost energy
W	W	%	W	W	W	W
	43200,00	15,00				
5000,00	38000,00	13,19	5200,00	0,00	0,00	0,00
5000,00	32800,00	11,39	5200,00	0,00	0,00	0,00
5000,00	28800,00	10,00	4000,00	0,00	1200,00	0,00
5000,00	28800,00	10,00	0,00	0,00	5000,00	0,00
5000,00	28800,00	10,00	0,00	0,00	5000,00	0,00
5000,00	28800,00	10,00	0,00	0,00	5000,00	0,00
5000,00	28800,00	10,00	0,00	0,00	1864,90	0,00
15000,00	40089,60	13,92	0,00	11289,60	0,00	0,00
20000,00	71076,48	24,68	0,00	30986,88	0,00	0,00
20000,00	115163,52	39,99	0,00	44087,04	0,00	0,00
20000,00	165898,56	57,60	0,00	50735,04	0,00	0,00
20000,00	191703,36	66,56	0,00	25804,80	0,00	0,00
20000,00	216049,92	75,02	0,00	24346,56	0,00	0,00
20000,00	235464,00	81,76	0,00	19414,08	0,00	0,00
20000,00	246043,20	85,43	0,00	10579,20	0,00	0,00
20000,00	250136,93	86,85	0,00	4093,73	0,00	0,00

Table 7 state of charge and resulting loads (own figure)

In Table 8 are the results of the whole program listed, here in the case of the load with reductions. The first column represents the whole energy which is supplied from the panels to the batteries and it is also given in percent here. The second column is similar to the first and shows how much energy can be supplied to the user. The sum of these two loads results in the whole energy supplied by the panels. It can be seen that the energy which is produced by the panels is more than the needed energy from the user. The average state of charge of the battery is about 46% over the whole year. This can vary along the years but does not give a deeper insight in the battery management over the whole year. This graphic also shows that the discharged and charged amount of energy must be the same over the whole year.

The most important values here are the load which must come from an external source which is also calculated in running hours/ day of the backup generator. But also, the lost energy which occur because of the full charged battery. There must be an equilibrium between these two factors. The load which is supplied by an external source should be minimized. This is possible by increasing the size of the batteries or by increasing the size of the panels. Both is only reasonable till a certain point, after this it will be more or less a waste of money. To reduce the lost energy because of full charged battery, the size of the battery can be risen or the PV panel size can be decreased.

RESULTS										
With Reduction										
	E_Grid	E User	E Panels	E Load	SOC Bat	Discharge Bat	Charge Bat	Load ext		Lost energy
Total	104,69	68,05	172,74	162,43	46,02%	83,35	83,37	14,29	0,98	17,13
	MWh	MWh	MWh	MWh	Average	MWh	MWh	MWh	h/day	MWh
Ratio /E Load	64,45%	41,90%	106,35%	-----	-----	51,32%	51,33%	8,80%		10,54%
	106,35%							-1,75%		

Table 8 Results of program (own figure)

4.7 Second option

The second option is to provide a solution for the whole system which meets nearly the whole energy needs. Also in this option the same inverters, PV panels and battery systems are used. It is not easy to supply the village with fuel and so it will be better to increase the system size and to reduce the running hours of the backup-generator. Here the aim was also to find out the numbers of hours, the backup generator has to work and to optimize it. As mentioned in the first option the aim was to meet the reduced energy needs and the maximum PV panel size was set to 100 kWp. Now the PV panel size is not fixed and there will be different attempts to get the best solution. There has been a PV panel size multiplicator introduced in the Excel file calculations for the battery system, which has been described earlier. The basis of the PV panel size was 102 kWp and there will be calculations till the double amount. Furthermore, a different number of battery packs was introduced to see how it will affect the distribution. Therefore, to find out with which option the backup generator works the most efficiently the number of hours in which the backup generator has to work, the PV panel size and the battery size has been introduced in a diagram as we can see it in Figure 18. It is shown that the energy supplied by the battery plays an important role in the dimensioning of the system. When only the PV panel size is increased drastically, the running hours of the backup generator does not decrease very much. So also, the number of batteries must be increased. This is efficient until a certain amount of batteries and then the behaviour is quite similar. As it can be seen in the graph an increase in battery size is efficient until 5 battery packs. Afterwards the running hours of the backup generator does not decrease much.

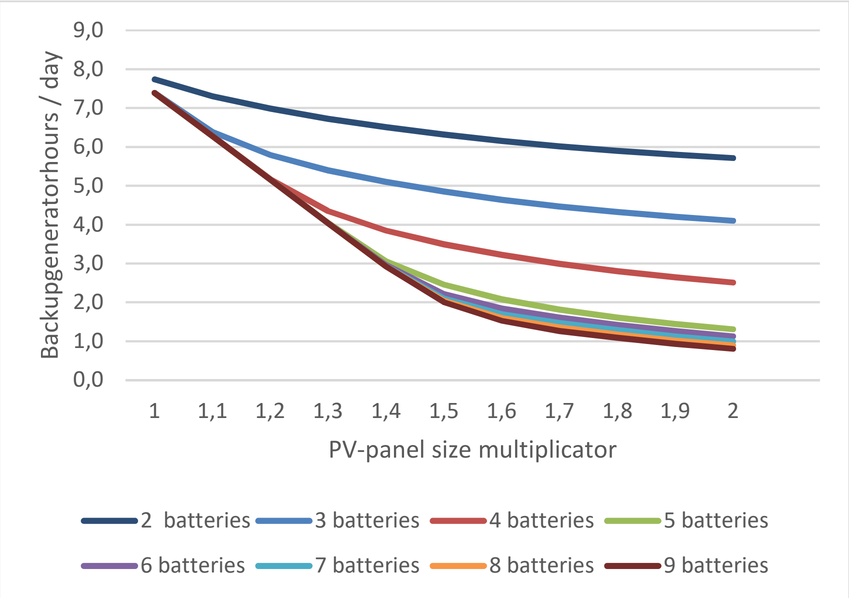

Figure 18 PV panel and battery sizing without reductions (own figure)

The amount of energy which is produced by the panels but cannot be saved in the batteries or used by the consumers is the lost energy, which can be seen in Figure 19.
Also, here it is shown that an increase of the battery packs to 5 units is useful but afterwards the losses are nearly the same. As mentioned before the running hours of the backup generator are not decreasing when just the PV panel size is increased. Additionally, there need to be more battery packs used. The losses increase significantly when the system size is doubled.
For this reason, there have been two attempts, one with the increased panel size of 1,6, another one with 1,8 and both are done with 5 battery units.

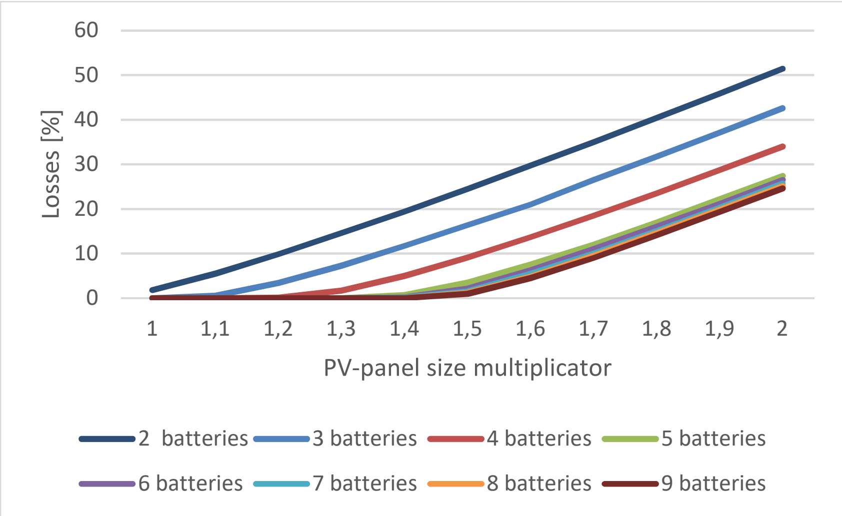

Figure 19 lost energy in PV system (own figure)

4.7.1 Panel size with factor 1,8

To introduce the panel factor with 1,8 into the system the panel size has been increased to 176 kWp at standard test conditions. Therefore, 28 strings of 20 panels in series, which is possible like mentioned in the first version, will be needed to meet the energy needs. In relation to this, 6 inverters are used to convert the energy. As mentioned before 5 battery units will be used to save the energy.
As we can see in Figure 20 the panels produce 296,36 MWh and the loads are 277,4 MWh, so more than the energy needs are covered with this attempt. The lost energy is about 12% of the energy production and cannot be used efficiently. But the load which would be needed from an external source is about 9 % and so quite low for the whole system. For this reason, the backup generator would be running about 1 h and 47 minutes. This will not be every day the same, because in this region rain seasons occur in which the backup generator has to work more. There will not occur any overload losses and the Pnom ratio has also a good value with 1,09. Here an area of 1087 m² will be needed to install the panels.

Without Reduction										
	E_Grid	E User	E Panels	E Load	SOC Bat	Discharge Bat	Charge Bat	Load ext		Lost energy
Total	154,96	141,38	296,34	277,40	44,30%	114,46	114,48	26,08	1,79	34,27
	MWh	MWh	MWh	MWh	Average	MWh	MWh	MWh	h/day	MWh
Ratio /E Load	55,86%	50,97%	106,83%	------	-----	41,26%	41,27%	9,40%		12,36%
	106,83%							-2,96%		

Figure 20 results with increased panel size by 1,8 (own table)

4.7.2 Panel size with factor 1,6

The second option was to set the panel factor to 1,6 and so the panel size has been set to 158 kWp. It is the same setting as in the version with the panel factor of 1,8 but there will be 25 strings with 20 panels in series instead of 28 strings. Furthermore only 5 inverters are needed to convert the energy. So, costs can be reduced with this option. The overload losses are 0,4% and the Pnom ratio is 1,17 which are acceptable values. It has also been tried to use 6 inverters, then there will be no overload losses and the Pnom ratio is 0,97 but it does not really help to produce significantly more energy.

In Figure 21 can be seen that the lost energy is 4,73% of the whole produced energy, which is a better value than in the version before. Therefore, more energy will be needed from an external source. Here the produced energy is only about 4% lower than the whole needed energy. Also, here the PV panel power is only at standard test conditions, but under real operating conditions at 1000 W/m² and 50°C it will be about 141 kW.

When we compare Figure 18 with the results of the running hours of the backup-generator in Figure 21 the calculation in excel is very similar to the simulation.

Without Reduction										
	E_Grid	E User	E Panels	E Load	SOC Bat	Discharge Bat	Charge Bat	Load ext		Lost energy
Total	128,05	138,33	266,38	277,40	40,37%	109,78	109,80	33,67	2,31	13,13
	MWh	MWh	MWh	MWh	Average	MWh	MWh	MWh	h/day	MWh
Ratio /E Load	46,16%	49,87%	96,03%	------	-----	39,57%	39,58%	12,14%		4,73%
	96,03%							7,40%		

Figure 21 results with increased panel size by 1,6 (own table)

Summarizing it can be said, that this version will be sufficient for supplying energy to the consumers and also the lost energy is not high. Furthermore, the costs can be reduced with this option, so it will be chosen for further investigation.

4.7.3 Connection of the panels

Also in this option, the inverters and safety equipment will be located in the north of the PV system as we can see in Figure 22.

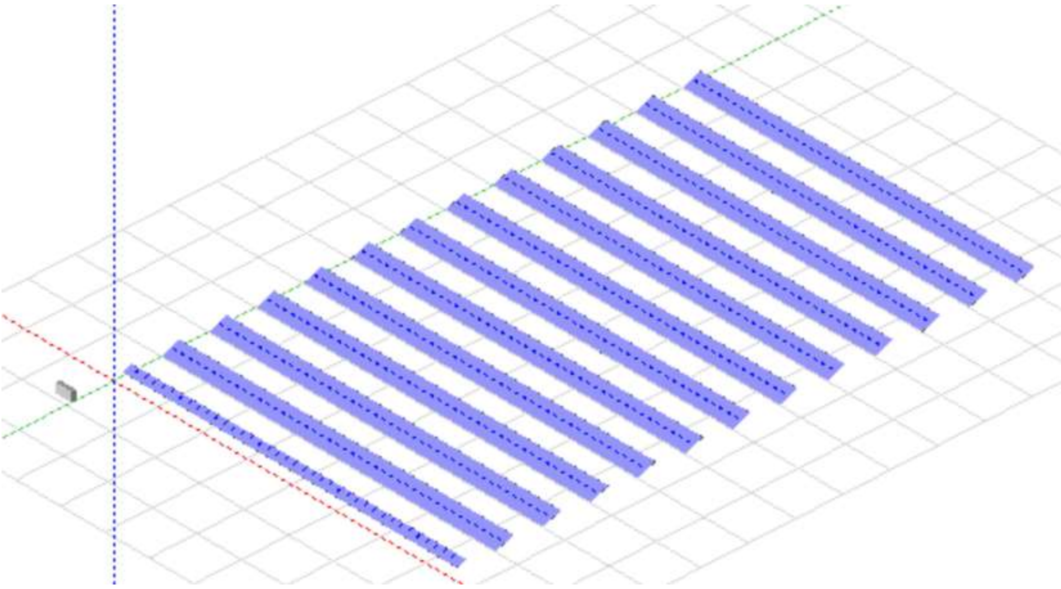

Figure 22 PV panels arrangement second attempt (own figure)

As stated in “4.5.3 Wiring” the best option is the first one where in each third raw a connection box will be used and also, the same layout will be used. 8 strings are added, and because of this the calculations need to be changed. There are 25 strings so there will be five strings per inverter, which is ideal for the inverters.

4.7.4 Wiring

1. Like in the first option the first wiring solution with 1 connection box in each 3rd raw will be used. There will be 5 boxes which are located at the left side of the whole system. The calculations of this boxes are similar to the ones in the first option. The only difference is that there will be three boxes which are similar to the first box, with 255 metres and two boxes with 235 metres, which occurs because of the different distances from the strings. Afterwards, 2% auxiliary are added and so 1260 meters of cable length with 25mm² will be the final length. From the boxes to the inverters 95mm² cables will be used and with an auxiliary of 2% the cable length will be 373 meters. This results in a copper mass of 7592 kg and a loss fraction of 1,5% which refers to the loss of voltage over the whole distance. This has been summarized in Table 9.

	from panels to box [m]	from box to inverter [m]	diameter [mm²]	Copper mass [kg]	Loss fraction [%]
variant 1	1260	372	25 / 95	7592	1,5

Table 9 wiring of the second option (own table)

The shadowing analysis is similar to the analysis in the first option, only the panel size increased, but the rest of the conditions stayed the same. So, this analysis will not be further documented in this option.
Furthermore, the wiring to the battery system will also be the same calculations as in the first option. The only difference here is that there are five inverters and so five or ten wires, depending on the size of the wires.

4.7.5 Summarization of the second option

It has been proven that this will be the best version for supplying the energy to the users. The running hours of the backup generator are 2 hours and 20 minutes per day and so in comparison to the running hours of the PV system quite small. These hours will variate over the year because of rain seasons and different irradiation of the sun. In the wiring of the system a huge amount of copper will be needed, which will rise the costs of the whole system. The cables need to have these sizes, because otherwise the losses would be too high.
The charge controllers will not be sufficient for the discharging process of the battery because the highest value which can occur will be 81 kW. Also for the charging of the system, there will occur a maximum charging power of 88 kW. For this reason, two charge controllers of the given 60kW or a different charge controller will be needed. To reduce the size of the cables it would be beneficial to split the powerplant in a few smaller ones, so the costs could be decreased and different supply points would be given. The maintenance and the construction would be a bit more difficult.

4.8 Losses

In every system losses occur even if the designers of the system plan it exactly. There is the need to reduce the losses to a minimum which is possible. In PV systems, different types of losses occur like thermal losses, ohmic losses dependent on the wiring, module quality losses, soiling losses, IAM losses and losses which occur because of the degradation of the panels. These losses are all introduced in the software PVsyst and so now they will be explained.

4.8.1 Thermal losses

The thermal behaviour of a panel has got a big influence on the electrical performance and it is dependent on the ambient temperature and also the cell temperature itself. The wind velocity also plays a part role in the thermal losses but they are very hard to define because it is fluctuating all day long. The thermal losses consist out of two components. Uc which is the constant component and Uv which is dependent on the wind velocity. They are set together as followed: $U = Uc + Uv * v$ here v is the velocity of the wind and the unit of this factor is $\frac{W}{m^2*K}$. The heat capacity of air is very low, so that a balance of the air temperature on and behind the panel is quite fast reached. There is a problem by taking the wind into account, because it is changing every time and there is no foresight in the wind velocity for the whole years. So, the experts which designed the software PVsyst set the value for Uv to 0 because it is not possible to foresight. In very windy regions like in coasts this value can be higher, but because Chifunda has not got a very windy climate we will stick to the standard conditions. The value for Uc depends on the installation like if it is free mounted, semi-integrated with air duct behind or fully integrated with an insulated back. For free mounted PV systems, this value is 29 $\frac{W}{m^2*K}$. (PVsyst-Array-Thermal-losses)

The NOCT coefficient is called the Nominal Operation Cell Temperature coefficient. This coefficient provides information over the temperature of the PV module which is attained when the air is circulating free around the panels under STC. Here the Irradiation is defined with 800W/m², an ambient temperature of 20°C and a wind velocity of 1m/s. This factor is only slightly dependent on the cover of the panels but they are normally quite the same for each panel. Researchers from NREL (National Renewable Energy Laboratory) have tested 3 different modules with different NOCT values and these have shown the same temperature within 0,2°C. Furthermore, this value is not given for the different types of mounting like free ventilated, integrated and insulated like mentioned before. So, we can conclude that this factor does not have any influence on the module temperature and so it can be neglected.

4.8.2 Module losses

The module quality loss parameter reflects the own expectations of the panels while also respecting the manufacturer´s specifications. At default value, it is set to -0,4 so an overperformance can assumed because Trina solar has got a positive performance tolerance. (PVsyst-module_quality_loss)

The Light Induced Degradation loss also called LID is a critical loss to involve. It arises when the panel is exposed to the sun in the first hours of use. This occurs because of the Oxygen which is captured in the cell. When the light hits the panel, the Oxygen can create complexes with the Boron dopants. So, these are building then electron holes in which some electrons can be captured and so the energy is lost for that number of electrons. It is well known that in the first few hours of introducing sunlight to the panel all parameters of the panel go slightly down. This loss lies normally in a range of 1% - 3%. In this PV system, it is set to 2%. (PVsyst-LID_loss)

For the Potential Induced Degradation (PIT) is the modules voltage potential and the leakage current responsible because they are driving ion mobility between the semiconductor and the other parts of the module like the frame and glass. This mobility is dependent on humidity temperature and voltage potential. But not only the environment is responsible also the system, the module and the cells play a role in PIT. The environment cannot be changed and so it is best to look at the system and the modules. For the system, the researchers have shown that the panel degradation has no interrelationship with the inverter principle. This means that it does not matter if the principle is based on symmetric ungrounded or grounded, ungrounded +AC or negative grounding etc. The higher the voltage of the AC part is the more it is possible that PIT is occurring. For the module, researchers have shown that it is critical which glass and diffusion barriers are chosen. For preventing PID, silicon dioxide has shown good results as a diffusion barrier. By the use of an antireflection coating on the front of the cell the power conversion can be risen but this occurs to be critical for the PID. (Advanced Energy)

The panel from Trina solar TSM-PD14 are certified to be resistant against PID so this factor will not play a role for the system.

4.8.3 Mismatch losses

The mismatch losses are basically due to different performances of photovoltaic panels. So, the worst panel is responsible for the output power of the whole string. It basically occurs when cells are connected in series and this already appears even in a panel by the series interconnection of the cells. Every single panel and cell operate differently and so also the I-U curves are not the same. Mostly low short circuit current Isc, or low open circuit voltage Uoc are responsible for a bad performance of the whole system. It also happens because of shading of single cells because of bird drops, leaves and dirt on the array. In Figure 23 the effect of the dissipated power because of the poor cell performance can be seen. Here the first cell would have the best performance but it is diminished by the second and even more by the third.

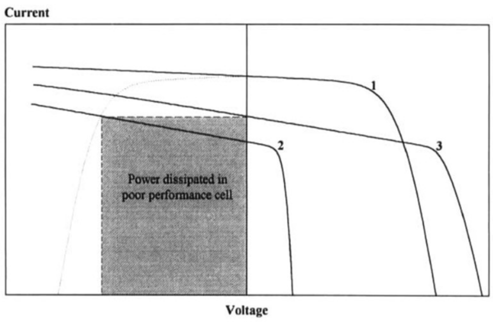

Figure 23 I-U curve with mismatch (David Roche et.al., 1994)

So, there are some solutions which lower these mismatch losses but do not make them disappear. The bypass diode is common to use in photovoltaic panels. Here maximal 23 cells are connected with a bypass diode which bridges these cells when one or more of them are shadowed. This limit is because of the breakthrough voltage of one cell which would be higher when more are connected in series and so the panel could be damaged. There must also be thoughts about the series and parallel circuit design of the system which can dramatically affect the output. For example, when a shadow is foreseen to hit the lower raw of the panels it is good to connect these lower panels in series and the upper panels also. As mentioned already, some manufacturers do flash tests to analyse the panel performance of each one. So, when they did a flash test the good cells and the bad cells can be put separately in a string to get the maximum out of each string.
(David Roche et.al., 1994)

In PVsyst it is possible to run a simulation of the resulting I-U cure of a whole string in the project. In Figure 24 can be seen how the mismatch losses affect the whole string. The green line shows the average characteristic without these losses and the black line takes the mismatch losses into account.

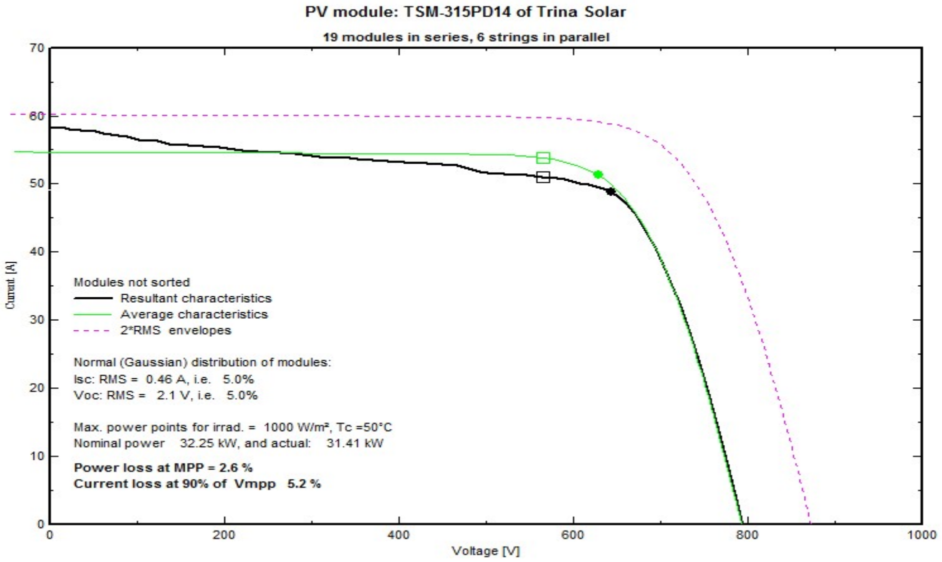

Figure 24 mismatch loss example TSM-315PD14 (own figure)

This is just a random example of PVsyst how the mismatch losses can affect the whole string to get a feeling for these losses. PVsyst offers also the option to create a histogram of different simulation as it has been seen in Figure 24.

In Figure 25 is shown that 240 simulations were analysed to get the average Pmpp loss and the current loss at a fixed voltage. This statistic gives a better overview about the expected losses and they can be implemented in PVsyst.

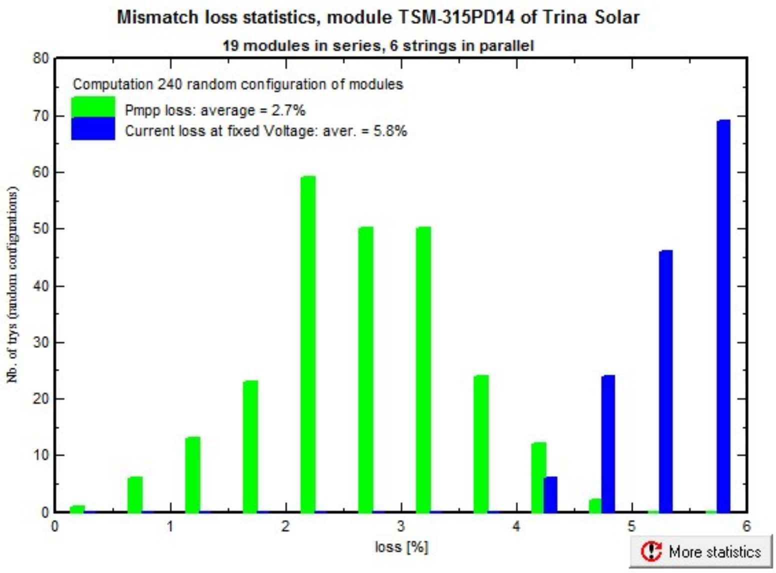

Figure 25 Mismatch loss statistic histogram TSM-315PD14 (own figure)

4.8.4 Soiling losses

Soiling is very dependent on the area in which the system is installed and so it is difficult to estimate the different values of soiling losses. These losses occur because of bird drops, leaves or dust which fall on the panels. Different researchers have found very different values while researching in this field. Rain has a big conjunction with these losses and researchers have found out that about 5mm of rain reduces the soiling losses to about 0,5%. Dust can be more or less easily washed away by rain but the big problem occurs with bird drops because they remain most of the time also in rain seasons on the panels. Another problem appears because of the growth of mosses and lichens at the frame of the modules. This can create a shadow on the lower cells and so more dust is caught at the bottom of the panels. Also, the pollution in the area in which the PV system is installed has got a certain influence on the soiling losses of the system. (Thevenard, 2010, pp. 22-23)
Like mentioned and shown in “Climate, weather and location” there is nearly no rain between the months April and October. As a result of this, the soiling losses will be higher in this months and will be then reduced in the following ones. The soiling losses are normally in a range of 1% - 3%. For this project they are set in the rain season from December until March to 1% and in the rest of the year to 2%.

4.8.5 IAM losses

IAM stands for Incidence Angle Modifier and it is corresponding to the decreased radiation which actually reach the PV module. These losses are due to the angle of the sun irradiation which hits the PV panel. Practically it can be calculated with the parametrisation of ASHRAE which is an American standard norm for which the formula is as follows:

$F_{IAM} = 1 – b_O * (1 / \cos(i) – 1)$

i …... incident angle on the plane

b_O … factor due to refraction (PV standard 0,05)

The program is automatically calculating the losses with these factors and adding it to the rest of the losses. They can also be specified but it is not further necessary here.
(PV syst IAM loss)

4.8.6 Auxiliaries

In the auxiliary energy losses, the energy which is needed for monitoring, fans, air conditioning is determined. In our case, it is not defined how much these systems will consume or if they will be even existing. So, these losses are not taken into account in the calculations.

4.8.7 Ageing

The ageing has a significant role in the PV sector and every manufacturer gives a warranty that the panel has got a certain efficiency after a few years. The normally assumed lifetime is about 25 years but if the system is well maintained it can even last longer than this period. Of course, it can also occur that the system does not last as long as the stated period of time because a failure in the system or a natural catastrophe. As we can see in Figure 26 the warranty of the manufacturer is about 91 % of the efficiency after 10 years, which is a quite usual value for PV panels.

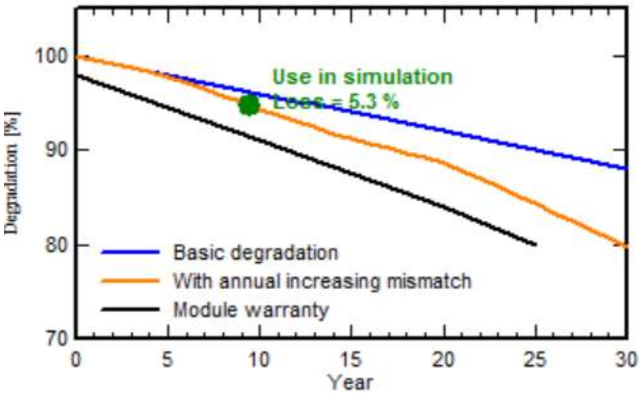

Figure 26 Ageing of the PV panels

Ageing of PV panels is due to two causes. First of all, the atmospheric conditions as sun, wind, rain or dust have a notable impact on the ageing. Second, is the internal component, where the quality of the different used materials rules the losses. In fact, the temperature also has got an influence on the degradation.

The simulation was done with 10 years because this is about half of the normal lifespan of a PV panel. In relation to this the losses are higher so in the beginning the system will produce more energy as the simulation says. As we can see the simulation does not take the minimum amount of the efficiency which would be 91 % so this value can vary over the lifespan of the panels. The average loss in efficiency of this panel is stated with about 0,72%/year.

4.8.8 Unavailability

The unavailability of a system is the period of time in which the system cannot provide energy because of maintenance or maybe even a failure in the system. This time fraction is set by default to 2% which means more or less seven and a half days in the year. The time which is needed here can be split up in the program to different numbers of periods. Here it was chosen to be three periods with each of 58 hours. It would be the optimum if the maintenance is made when there is no sun available at this day or that it is only at night time. This will not be possible every time and the maintenance periods will take more time because of the size of the whole system. That periods must be planned to occur in the lifespan of a PV system and are necessary to take into account.

4.9 Mounting system

There are different systems available for mounting the photovoltaic panels.
The concrete foundation is conducted in streak- or in point- foundations. A connecting plate allows a quick installation of the photovoltaic system.
Pile-driven foundations are also an option here the hot-galvanized steel is rammed or screwed into the earth by a machine. This saves material and labour costs in comparison to the concrete foundation.
The rail system is made out of aluminium and there is the possibility of a one-post system or a two-post system with an N-form. The two-post system is made for more module rows, so for this project a one-post system with stiffening is sufficient.
For these systems Schletter GmbH is a company which has specified in this area of mounting systems.

4.10 Safeguards

4.10.1 Lightning protection

The lightning protection is a significant topic in large scale PV power plants. The EN 62305-2 should be considered to get the maximal available security for the whole system.
PV power plants demand a big area of square meters and in the surrounding it is good when no shading scenes occur. Because of this there is a big area with nearly no increased points in the surrounding. Here the danger of a lightning strike is given and the resulting damage need to be minimized. The basis for calculation of lightning strikes is given by the size of the PV power plant, the location and the regional lightning frequency. Danger occurs with direct lightning strikes and also with induced voltage as a result of the electromagnetic lightning field. When the system is damaged, it need to be replaced or repaired. The impulses of lightning also cause ageing of the bypass diodes and the semiconductors. Also, the availability of the system is a significant point because if the system for example in the village do not provide the energy for the users, all the people will not be supplied with electricity. Then there would be only the backup system which cannot provide as much energy because it is normally just used for covering the rest of the energy needs.
For these reasons, a lightning protection system is required. There are different methods for this system and one of it is the rolling sphere method. Here it can be calculated how much air-termination rods will be needed. The generator junction boxes which connect the different strings in the rows shall be installed on the module rack. It is advisable that the inverters are as far as possible off the air-termination system. This is because of the electromagnetic lightning field. Another point is that terminal lugs need to be corrosion-resistant because the corrosion would reduce the diameter of the metal in which the current has the possibility to flow. So, also the earth resistance need to be stable over the years of operation of the PV powerplant in this case the influence of corrosion, soil moisture and frost are the most relevant. The air-termination system can be connected with the earth-termination system with pile-driven

foundations. An earth protection system is by all means necessary and forms the basis to protect the system against lightnings strikes and surge. For this reason, there need to be a mesh in the earth of 20 m x 20 m or 40 m x 40 m to hold the earth resistance lower than 10 Ω. This mesh is buried under the frost line and it consists out of a meshed 10mm² stainless steel. Depending on the conductance of the module racks they can also be connected to be part of the mesh. When the external lightning protection is installed it need to be taken into account that the solar cells are not shaded by the air-termination rods. If diffuse shadows occur they do not negatively affect the system, but core shadows must be prevented, because they will stress the cell, the bypass diode and also reduce the energy production. When the distance between solar module and the air-termination system of 10mm² diameter is greater than 1,08m there will only be a diffuse shadow on the module. This system will be built up as it can be seen in Figure 27.

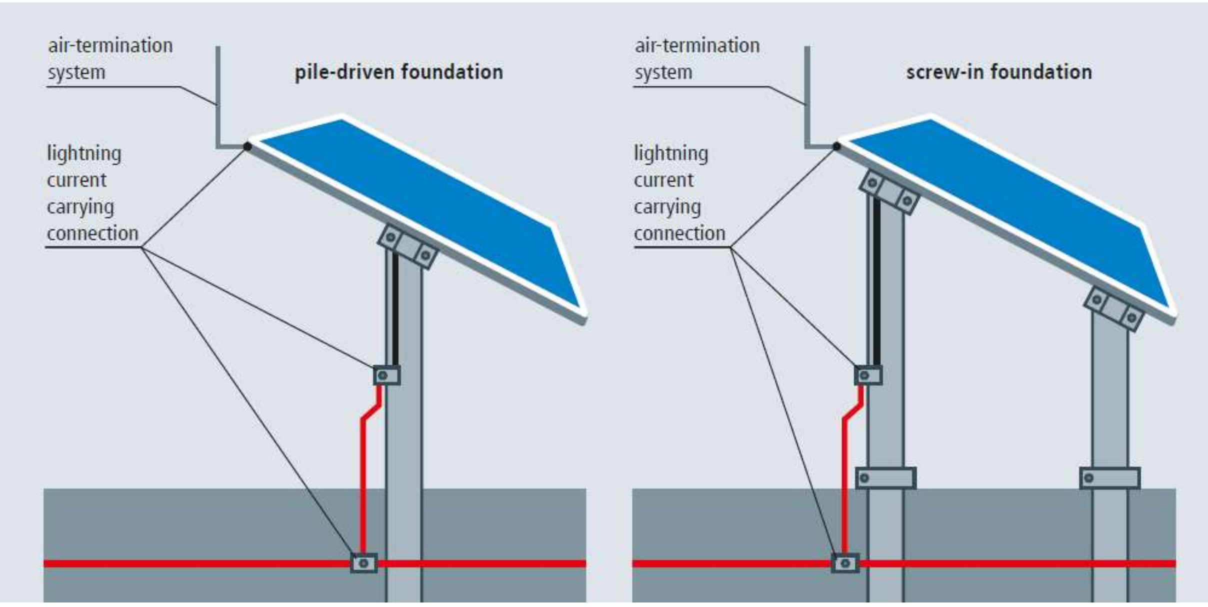

Figure 27 air- and earth termination sytsem (Dehn international)

In lightning protection systems occur different classes. 1 is the highest and 4 is the lowest, for photovoltaic systems 3 is recommended. Here the peak lightning current value minimum is 10 kA and the maximum is 100 kA. In this case the capture probability is 88%. (OBO) In this case, if the protection system is one to two meters high the protective angle will be 76°.

In Figure 28 and Figure 29 the angle and the number of air-terminal systems per table can be seen. In this case with 20 panels in series 6 air-terminal systems would be needed with a height of 1,2 metres.

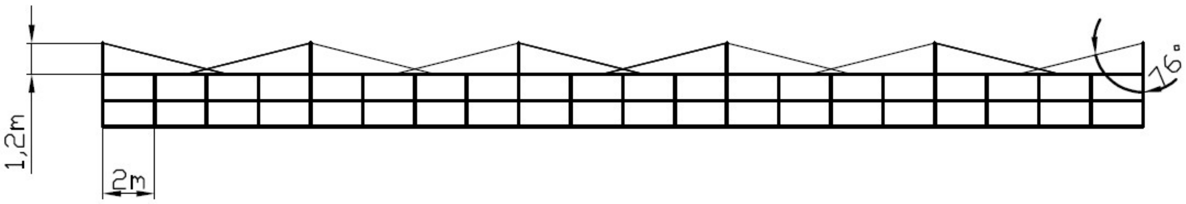

Figure 28 Lightning protection 1 (own figure)

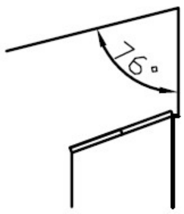

Figure 29 Lightning protection 2 (own figure)

Another aspect is the conductor routing of the PV panels. Here large conductor loops must be prevented because here occurs a high risk of surge. The arrester has different tasks like to protect the surge protective device due to insulation faults in the PV circuit, to prevent fire because of an overloaded arrester and also to minimize small voltage peaks.

In Addition to surge and lightning protection it would be good to have an option for remote maintenance by the plant operator. So, to have a possibility to do remote diagnostics and because of this reliable data transfer would be needed. The monitoring of string and inverters as well as weather data are a significant part.

4.10.2 High voltage protection

For this type of protection are different types available.

- Type 1: Protection against intrusion of lightning currents, but no protection against high voltage
- Type 2: Protection against fluctuation voltage and protection against descend to a lower level.
- Type 3: Protection against fluctuation voltage and protection against descend to an even lower level.

Therefore, a PV surge arrester IS011250-A Photec C 550/12,5 was used from the company Schrack. It has got the type 2 and a nominal discharge current of 20 kA and a permanent voltage of 1000V. This will be connected in the connection boxes, and for each string there will be one needed. Furthermore, before connecting it to the inverter there will be also one for each cable needed. The exact information can be taken from the attached datasheet.

4.10.3 String protection

A string protection is necessary in bigger photovoltaic systems, because if an error occurs they protect the strings against destruction. For this reason, with 25 strings 25 string protection fuses are used with a permanent voltage of 1000 V and a current of 10 A. So, the protection is slightly higher than the short circuit current of the panels with 9 A, but it will be sufficient because the maximum current in the panel is 15 A.

4.10.4 Switch disconnector

For the alternating current (AC) side of the inverters switch disconnectors are needed to disconnect the user from the panels. Therefore, the load break switch from ABB with the name OT100F4N2 will be used. This is a 4-pole switch and is able to switch 100A. Further information can be read in the attached datasheet.

5 Summary and future view

There have been two concepts implemented to cover once the essential reduced energy needs and also to cover the whole energy needs. For about 400 households, a mil, a school, shops and a few refrigerators the essential reduced energy needs can be covered by 17 strings of 19 panels in series to 91% and account to 162,4 MWh. Therefore, four battery packages with a capacity of 332 kWh and one charge regulator of 60 kW will be needed. Here the backup generator would be only needed about 1 hour per day but also the lost energy would be around 10,5%.

If the whole energy demands need to be supplied by these panels with a size of 102 kWp, it does not make sense because there would be about 40 % of the whole demands needed to be supplied by the backup generator. In the case that the panel size is not increased it would be sufficient to use 2 units of batteries with a total capacity of 166 kWh.

The whole energy needs of the town account to 277,4 MWh can be covered to 88 % from 25 strings and 20 panels in a series. Furthermore, five battery packages with a whole capacity of 415 kWh and two charge regulators of 60 kW, or one with 88 kW, would be necessary for this solution. In this solution, the backup generator would be needed 2 hours and 20 minutes a day. Also, the lost energy would be only 4,7% of the whole production.

For the second option the price for the components and the wiring will be much higher but so in this case a powerplant is installed which can supply nearly the whole energy needs.

If this system would be installed in this area the lifestyle of the people would be risen significantly. This project would be a good opportunity as a pilot project to initiate the rural electrification in that area.

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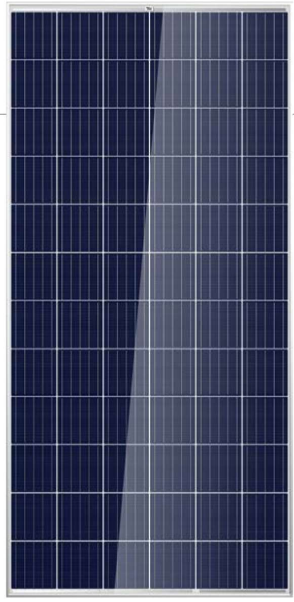
Attachements:

Mono Multi Solutions

THE TALLMAX MODULE



72 CELL
MULTICRYSTALLINE MODULE

310-325W
POWER OUTPUT RANGE

16.8%
MAXIMUM EFFICIENCY

0~+5W
POSITIVE POWER TOLERANCE

As a leading global manufacturer of next generation photovoltaic products, we believe close cooperation with our partners is critical to success. With local presence around the globe, Trina is able to provide exceptional service to each customer in each market and supplement our innovative, reliable products with the backing of Trina as a strong, bankable partner. We are committed to building strategic, mutually beneficial collaboration with installers, developers, distributors and other partners as the backbone of our shared success in driving Smart Energy Together.

Trina Solar Limited
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Trinasolar
Smart Energy Together

Ideal for large scale installations
- High power footprint reduces installation time and BOS costs
- 1000V UL/1000V IEC certified

One of the industry's most trusted modules
- Field proven performance
- Strong, reliable supplier

Highly reliable due to stringent quality control
- Over 30 in-house tests (UV, TC, HF, and many more)
- In-house testing goes well beyond certification requirements
- 100% EL double inspection

Certified to withstand challenging environmental conditions
- 2400 Pa wind load
- 5400 Pa snow load
- 35 mm hail stones at 97 km/h
- PID resistant

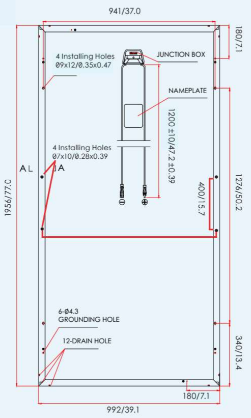
Comprehensive products and system certificates

- IEC 61215/ IEC 61730/ UL 1703/ IEC 61701/IEC 62716
- ISO 9001: Quality Management System
- ISO 14001: Environmental Management System
- ISO 14064: Greenhouse Gases Emissions Verification
- OHSAS 18001: Occupation Health and Safety Management System

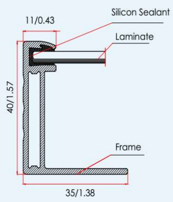
THE TALLMAX MODULE

TSM-PD14

DIMENSIONS OF PV MODULE unit:mm/inches

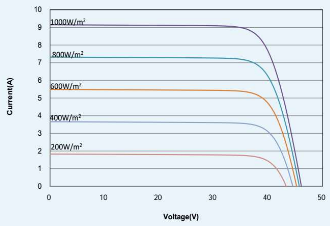


Back View

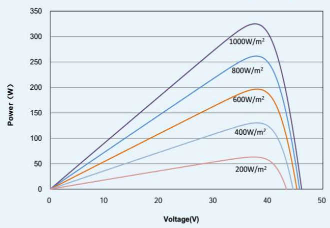


A-A

I-V CURVES OF PV MODULE(325W)



P-V CURVES OF PV MODULE(325W)



ELECTRICAL DATA (STC)

Peak Power Watts-P_{MAX} (Wp)*	310	315	320	325
Power Output Tolerance-P_{MAX} (W)	0 ~ +5			
Maximum Power Voltage-V_{MPP} (V)	37.0	37.1	37.1	37.2
Maximum Power Current-I_{MPP} (A)	8.38	8.51	8.63	8.76
Open Circuit Voltage-V_{OC} (V)	45.5	45.6	45.8	45.9
Short Circuit Current-I_{SC} (A)	8.85	9.00	9.10	9.25
Module Efficiency η_m (%)	16.0	16.2	16.5	16.8

STC: Irradiance 1000 W/m², Cell Temperature 25°C, Air Mass AM1.5.
*Test tolerance: ±3%.

ELECTRICAL DATA (NOCT)

Maximum Power-P_{MAX} (Wp)	230	234	238	242
Maximum Power Voltage-V_{MPP} (V)	34.3	34.3	34.4	34.5
Maximum Power Current-I_{MPP} (A)	6.72	6.83	6.91	7.02
Open Circuit Voltage-V_{OC} (V)	42.2	42.3	42.5	42.6
Short Circuit Current-I_{SC} (A)	7.15	7.27	7.35	7.47

NOCT: Irradiance at 800 W/m², Ambient Temperature 20°C, Wind Speed 1 m/s.

MECHANICAL DATA

Solar Cells	Multicrystalline 156 × 156 mm (6 inches)
Cell Orientation	72 cells (6 × 12)
Module Dimensions	1956 × 992 × 40 mm (77.0 × 39.1 × 1.57 inches)
Weight	22.5 kg (49.6 lb)
Glass	3.2 mm (0.13 inches), High Transmission, AR Coated Tempered Glass
Backsheet	White
Frame	Silver Anodized Aluminium Alloy
J-Box	IP 67 or IP 68 rated
Cables	Photovoltaic Technology Cable 4.0mm² (0.006 inches²), 1200 mm (47.2 inches)
Connector	MC4 Compatible or Amphenol H4/UTX
Fire Type	Type 1 or Type 2

TEMPERATURE RATINGS

Nominal Operating Cell Temperature (NOCT)	44°C (±2°C)
Temperature Coefficient of P_{MAX}	- 0.41%/°C
Temperature Coefficient of V_{OC}	- 0.32%/°C
Temperature Coefficient of I_{SC}	0.05%/°C

MAXIMUM RATINGS

Operational Temperature	-40~+85°C
Maximum System Voltage	1000V DC (IEC) 1000V DC (UL)
Max Series Fuse Rating	15A

WARRANTY

10 year Product Workmanship Warranty

25 year Linear Power Warranty

(Please refer to product warranty for details)

PACKAGING CONFIGURATION

Modules per box: 26 pieces

Modules per 40' container: 572 pieces

TSM_EN_2016_D

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Fronius

FRONIUS ECO

/ The compact project inverter for maximum yields.

/ SnapINverter Technology / Integrated data communication / Smart Grid Ready / Dynamic Peak Manager / Zero feed-in

/ The three-phase Fronius Eco in power categories 25.0 and 27.0 kW perfectly meets all the requirements of large-scale installations. Thanks to its light weight and SnapINverter mounting system, this transformerless device can be installed quickly and easily either indoors or outdoors. This inverter range is setting new standards with its IP 66 protection class. Furthermore, thanks to its integrated double fuse holders and optional overvoltage protection, string collection boxes are no longer necessary.

TECHNICAL DATA FRONIUS ECO

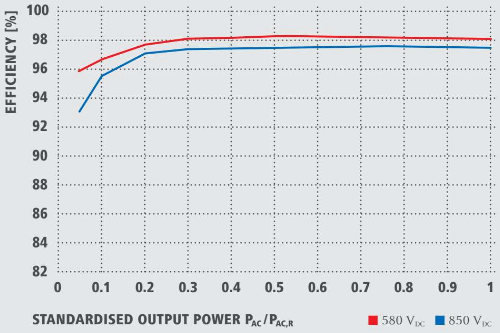
INPUT DATA	FRONIUS ECO 25.0-3-S	FRONIUS ECO 27.0-3-S
Number of MPP trackers	1	
Max. input current ($I_{dc\ max}$)	44.2 A	47.7 A
Max. array short circuit current	71.6 A	
DC input voltage range ($U_{dc\ min}$ - $U_{dc\ max}$)	580 - 1,000 V	
Feed-in start voltage ($U_{dc\ start}$)	650 V	
Usable MPP voltage range	580 - 850 V	
Number of DC connections	6	
Max. PV generator output ($P_{dc\ max}$)	37.8 kW_{peak}	

OUTPUT DATA	FRONIUS ECO 25.0-3-S	FRONIUS ECO 27.0-3-S
AC nominal output ($P_{ac,r}$)	25,000 W	27,000 W
Max. output power	25,000 VA	27,000 VA
AC output current ($I_{ac\ nom}$)	37.9 A / 36.2 A	40.9 A / 39.1 A
Grid connection (voltage range)	3-NPE 380 V / 220 V or 3-NPE 400 V / 230 V (+20 % / - 30 %)	
Frequency (frequency range)	50 Hz / 60 Hz (45 - 65 Hz)	
Total harmonic distortion	< 2.0 %	
Power factor (cos $\varphi_{ac,r}$)	0 - 1 ind. / cap.	

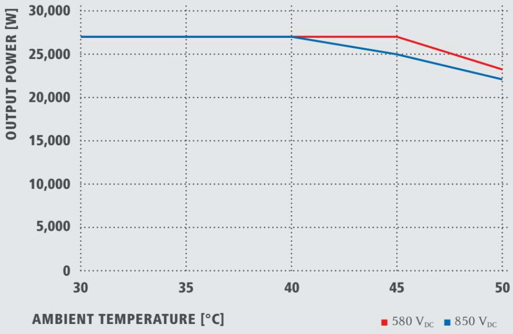
GENERAL DATA	FRONIUS ECO 25.0-3-S	FRONIUS ECO 27.0-3-S
Dimensions (height x width x depth)	725 x 510 x 225 mm	
Weight	35.7 kg	
Degree of protection	IP 66	
Protection class	1	
Overvoltage category (DC / AC) [2)]	2 / 3	
Night-time consumption	< 1 W	
Inverter concept	Transformerless	
Cooling	Regulated air cooling	
Installation	Indoor and outdoor installation	
Ambient temperature range	-25 - +60 °C	
Permitted humidity	0 to 100 %	
Max. altitude	2,000 m	
DC connection technology	6x DC+ and 6x DC- screw terminals 2.5 - 16 mm²	
AC connection technology	5-pole AC screw terminals 2.5 - 16 mm²	
Certificates and compliance with standards	ÖVE / ÖNORM E 8001-4-712, DIN V VDE 0126-1-1/A1, VDE AR N 4105, IEC 62109-1/-2, IEC 62116, IEC 61727, AS 3100, AS 4777-2, AS 4777-3, CER 06-190, G59/3, UNE 206007-1, SI 4777, CEI 0-16, CEI 0-21	

[2)] According to IEC 62109-1. DIN rail for optional type 1 + 2 or type 2 surge protection device available.
Further information regarding the availability of the inverters in your country can be found at **www.fronius.com**.

FRONIUS ECO 27.0.3-S EFFICIENCY CURVE



FRONIUS ECO 27.0.3-S TEMPERATURE DERATING



TECHNICAL DATA FRONIUS ECO

EFFICIENCY	FRONIUS ECO 25.0-3-S	FRONIUS ECO 27.0-3-S
Max. efficiency	98.2 %	98.3 %
European efficiency (ηEU)	98.0 %	98.0 %
MPP adaptation efficiency	> 99.9 %	

PROTECTION DEVICES	FRONIUS ECO 25.0-3-S	FRONIUS ECO 27.0-3-S
DC insulation measurement	Yes	
Overload behavior	Operating point shift, power limitation	
DC disconnector	Yes	
Integrated string fuse holders [1]	Yes	
Reverse polarity protection	Yes	

INTERFACES	FRONIUS ECO 25.0-3-S	FRONIUS ECO 27.0-3-S
WLAN / Ethernet LAN	Fronius Solar.web, Modbus TCP SunSpec, Fronius Solar API (JSON)	
6 inputs and 4 digital inputs/outputs	Interface to ripple control receiver	
USB (A socket) [2]	Datalogging, inverter update via USB flash drive	
2x RS422 (RJ45 socket) [2]	Fronius Solar Net	
Signalling output [2]	Energy management (floating relay output)	
Datalogger and Webserver	Included	
External input [2]	S0 meter connection / Evaluation of overvoltage protection	
RS485	Modbus RTU SunSpec or meter connection	

[1] Optionally fitted with 6 fuses 15 A / 1,000 V on the plus side. [2] Also available in the light version.
Further information and technical data can be found at **www.fronius.com.**

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M,06,0183,EN v12 Feb 2017 as17

OT100F4N2

General Information

Extended Product Type:	OT100F4N2
Product ID:	1SCA105018R1001
EAN:	6417019391496
Catalog Description:	OT100F4N2 switch-disconnector
Long Description:	4-pole, front operated, base mounted, DIN-rail mountable switch-diconnector / non-fusible diconnect switch with protected clamp terminals, handle and shaft are not included

Categories

Products » Low Voltage Products and Systems » Switches » Switch Disconnectors

Ordering

Minimum Order Quantity:	10 piece
Customs Tariff Number:	85365080

Popular Downloads

Data Sheet, Technical Information:	1SCC301020C0201

Dimensions

Product Net Width:	97 mm
Product Net Height:	100 mm
Product Net Depth:	74 mm
Product Net Weight:	0.5 kg

Technical

Rated Operational Current AC-21A (I_e):	(380 ... 415 V) 100 A (500 V) 100 A (690 V) 100 A
Rated Operational Current AC-22A (I_e):	(380 ... 415 V) 100 A (500 V) 100 A (690 V) 100 A
Rated Operational Current AC-23A (I_e):	(500 V) 60 A (380 ... 415 V) 80 A (690 V) 40 A
Rated Operational Power AC-23A (P_e):	(380 ... 415 V) 37 kW (500 V) 37 kW (690 V) 37 kW
Conventional Free-air Thermal Current (I_{th}):	q = 40 °C 115 A
Conventional Thermal Current (I_{the}):	Fully Enclosed 115 A
Rated Impulse Withstand Voltage (U_{imp}):	8 kV
Rated Insulation Voltage (U_i):	750 V
Rated Operational Voltage:	750 V
Rated Short-Circuit Making Capacity (I_{cm}):	(690 V AC) 3.6 kA
Rated Short-time Withstand Current (I_{cw}):	for 1 s 2.5 kiloampere rms
Power Loss:	at Rated Operating Conditions per Pole 4 W at Rated Operating Conditions per Pole 0.36 W
Pollution Degree:	3
Handle Type:	Knob, Handle and shaft not included
Fourth Pole Position:	Right Side
Fourth Pole Type:	Switched - Simultaneous Function
Switches Operating Mechanism:	Mechanism on Top of the Switch
Distance Between Phases:	Standard
Position of Line Terminals:	Top In - Bottom Out Bottom In - Top Out
Operating Mode:	Front operated
Standards:	IEC 60947-3, UL 98 / CSA C22.2 NO.4
Special Functions:	No
Mounting Type:	Base mounting
Number of Poles:	4

Cable Cross-Section:	10 … 70 mm²
Terminal Type:	Screw Terminals
Tightening Torque:	6 N·m

Technical UL/CSA

Maximum Operating Voltage UL/CSA:	600 V
Horsepower Rating UL/CSA:	(acc. to UL 200 V) 25 Hp (acc. to UL 480 V) 50 Hp (acc. to UL 240 V) 30 Hp (acc. to UL 208 V) 25 Hp (acc. to UL 600 V) 50 Hp
Ampere Rating UL/CSA:	100 A
Tightening Torque UL/CSA:	55 in·lb

Environmental

Environmental Information:	1SCC301183D0201

Certificates and Declarations (Document Number)

Declaration of Conformity - CE:	1SCC301168D2702
Instructions and Manuals:	1SCC301058M0001
RoHS Information:	1SCC301183D0201

Container Information

Package Level 1 Units:	1 piece
Package Level 1 Width:	109 mm
Package Level 1 Length:	112 mm
Package Level 1 Height:	86 mm
Package Level 1 Gross Weight:	0.5 kg
Package Level 1 EAN:	6417019391496

Classifications

Object Classification Code:	Q
ETIM 5:	EC000216 - Switch disconnector
ETIM 6:	EC000216 - Switch disconnector

DATENBLATT / DATA SHEET: ÜBERSPANNUNGSABLEITER FÜR PHOTOVOLTAIKANLAGEN/ / OVERVOLTAGE PROTECTIVE DEVICE FOR PHOTOVOLTAIC APPLICATION

TECHNISCHE DATEN / TECHNICAL DATA

ART.NO. / BEZEICHNUNG	IS011250-A PHOTEC C 550/12,5	IS011251-A PHOTEC C 550/12,5+H	IS011210-A PHOTEC C 1000/12,5	IS011211-A PHOTEC C 1000/12,5+H
Geprüft nach / acc. to	Testclass II (C) EN 50539-11, IEC61643-1/EN61643-11			
max. Dauerspannung (DC) / max. continuous voltage (DC)	600Vdc	600Vdc	1000Vdc	1000Vdc
Kurzschlussfestigkeit / short circuit resistance I_{SCWPV}	1000A	1000A	1000A	1000A
max. Ableitstoßstrom / max. discharge current (8/20) I_{max}	40kA	40kA	40kA	40kA
Nennableitstoßstrom / nominal discharge current (8/20) I_n	20kA	20kA	20kA	20kA
Schutzpegel / protection level U_p (at I_n)	<2,2kV	<2,2kV	<2,8 kV	<2,8 kV
Folgestrom / following current I_f	---	---	---	---
Ansprechzeit / response time	<25ns	<25ns	<25ns	<25ns
Reststrom / residual current at U_c	<1,5mA	<1,5mA	<1,5mA	<1,5mA
Thermische Trennvorrichtung / thermal protection	Yes	Yes	Yes	Yes
Max. Anzugsmoment / terminal cross section	4,5Nm	4,5Nm	4,5Nm	4,5Nm
TOV für unbegrenzte Zeit standhalten / TOV unlimited time	1,5 x U_{CPV}			
Temperaturbereich / temperature range	-40°C - +80°C			
Klemmenquerschnitt / terminal cross section	35mm² (eindrähtig/solid) 25mm² (feindrähtig/stranded)			
Montage / mounting	35mm DIN Schiene/DIN rail			
Schutzart / degree of protection	IP20			
Gehäusematerial / housing material	Thermoplastic, extuishing degree UL94 V-0			
Breite / dimensions (DIN43880)	2TE			

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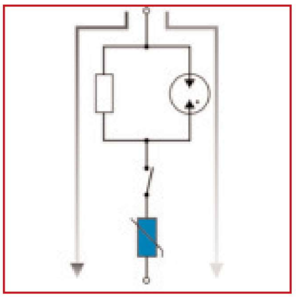
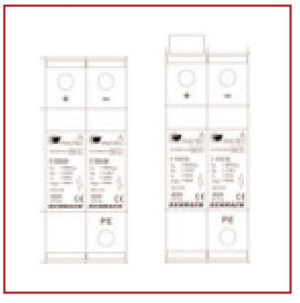
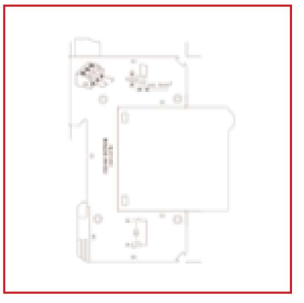
ART.NO. / BEZEICHNUNG	IS011250-A PHOTEC C 550/12,5	IS011251-A PHOTEC C 550/12,5+H	IS011210-A PHOTEC C 1000/12,5	IS011211-A PHOTEC C 1000/12,5+H
Hilfskontakt/remote control	---	Yes	---	Yes
Kontaktbelastung/ contact ratings	---	250Vac/0,5A 125Vac/3A	---	250Vac/0,5A 125Vac/3A
Klemmquerschnitt/terminal cross section	---	max. 1,5mm²	---	max. 1,5mm²
Max. Drehmoment/max. terminal torque	---	0,25Nm	---	0,25Nm

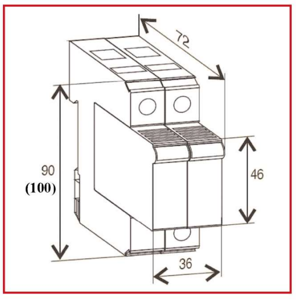
SCHEMATISCHE DARSTELLUNGEN / CIRCUIT DIAGRAMS







ABMESSUNGEN / DIMENSIONS



ERSATZMODULE / MODULES TO REPLACE DAMAGED MODULES

1000VDC: IS011253-A
550VDC: IS011252-A

ACHTUNG:
Überspannungsableiter müssen auf die maximal auftretende Spannung ausgelegt werden.
Höhere Leerlaufspannungen bei niedrigeren Temperaturen müssen berücksichtigt werden.

Surge arresters must be designed for the maximum voltage appearing.
Higher open circuit voltages at lower temperatures must be taken into account.