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Industrial Electrical Engineering and Automation

The effects of international standards on the design of a micro grid in a rural area

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MASTER THESIS

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Preface

This report is a Master thesis at the Lund University, as a part of a Master in Energy and Environment within the program Electrical Engineering. It was carried out during the spring of 2017, from January to May in co-operation between Lund University and ÅF International. ÅF has, with their global knowledge of electrical systems, helped to developed this Master thesis and its purposes. The majority of the project has been carried out at ÅF and has been supervised by Neil Hancock at ÅF International in Malmö. The project was created from a basic idea of working with micro grids in developing countries in Africa, Asia and south America.

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Acknowledgment

I would like to state my gratitude to ÅF for giving me the opportunity to develop and write my Master Thesis with them. Special thanks to my supervisor Neil Hancock for guiding me in the process, for helping me with all occurring problems and for letting me learn and develop a knowledge not only within power systems but also from a commercial point of view. I would also like to thank the other employees at ÅF who have been giving me a nice and inspiring environment to work in, and who has always been supportive and helpful, especially Gabriela Rystrand who helped me with a large part of the project. From LTH, I would like to thank Reza Safari who took time and helped me with the construction of a model in Power Factory. Last, but not least, I would like to thank the professor and my supervisor at LTH, Olof Samuelsson, who has commented and questioned my work, which has been of great benefit to the technical aspects in the thesis.

Lund, 2017-06-01

Magdalena Sandung

Abstract

The energy sector in the world today is in the middle of a huge challenge regarding grid development and power production. Whilst a significant part of the world's population are struggling without access to electricity, the more developed part of the world is trying to replace existing energy sources into renewable ones, and are also facing the challenge of an aging grid which is in desperate need of reconstruction. The technology and knowledge is not found everywhere and to be able to help other countries in their way towards functioning grids and renewable energy sources, well developed standards are very important for maintaining quality but also for inter-connection of grids in the world.

This thesis investigates the differences between existing standards in Sweden and Venezuela, by applying them on the design of a fictitious grid and comparing the technological and economical outcome of it. The grids are designed for a village in Venezuela, but with two different load profiles and with the two different countries' standards. The focus is put on standards regarding voltages, frequency, cable structure and short circuit currents, which are the standards with the most relevance in a simulation study. The simulation model is built in PowerFactory, a grid calculation program, and four different grids have been built in order to cover all scenarios. The simulations in the program shows voltage deviation, electrical loading, losses and short circuit currents, and are all part of the purpose to design a functioning grid. An economical analysis has been made for each grid, with cost calculations developed at ÅF and from sources in Venezuela.

The investigation about the standards in the two countries immediately points out the lack of standards in Venezuela. The country's grid development seems to be mostly based on experience and guidelines, which has caused several problems when trying to the design the grids. Swedish standards are plenty and all collected in books and documents, and they cover all basic grid structures and methods. The standards in Venezuela can all be found in one document, which covers a few basics, but is more focused on specific event and scenarios. This complicates the development of the grid. There are also some standards that affect the whole system and causes problems, but that can not be changed easily, as the voltage. The simulations show that the decreased voltage (compared to the Swedish voltage level) leads to higher currents, which in turn causes higher losses and heavier electrical loading on the cables. Since the cables in Venezuela use copper conductors, the cost is already high, but with a heavy electrical loading, the cables will not last for long and the replacement of them will cause even higher costs. The increased current also caused a high voltage drop and in order to solve all these problems, and to keep the same standard and quality as the Swedish grids, the cables needed to be thicker in order to be dimensioned properly. Larger cables are more expensive, and since they already play a huge role in the total cost calculation, it is quite negative.

Looking at the economical differences in the grids, the Venezuelan grid only uses copper cables, which is known to be much more expensive than aluminium cables, used in the Swedish grids. Thereby, a large difference can bee seen in the cable costs, where the Venezuelan cables cost more than the entire Swedish grids, including digging, trucks, transformer stations and much more. Comparing the two load profiles, it shows that a larger grid does not significantly affect the total costs. The cost calculations shows that for a Swedish company, it could be an option to enter the electricity market of Venezuela. The question would be weather to adopt the Venezuelan standards, and work with the main grid, or not adopt the Venezuelan standards and see if there is a possibility to work only with islanded micro grids. It could be an option to work within their standards but with Swedish cable structure, and change the copper cables into aluminium cables, to reduce the costs.

The ease of using Swedish grid design, the functionality and the total costs of the grids, points out the fact that well developed standards are very important when expanding old grids or building new ones. If more countries put focus on the development of international standards, all compatible with each other, it will expand the market in such way that the design and construction of grids in developing countries will be much easier. It will open up the market for foreign companies, that can contribute with their knowledge and experience, in order to speed up the development and create access to electricity to more people in the world. It will also create an easier way to ensure inter-connectivity inside of and between countries.

Contents

Chapter 1

Introduction

The importance regarding standards and the development of new standards is being more and more highlighted today. With technological development around the corner, rules and guidelines will be a corner-stone for creating a sustainable society. When new technology is being developed, the standards will ensure the inter-connectivity of the already existing technology, and ease the transition to the future products and methods. The development of international standards will help building bridges between countries in order to share knowledge and experience.

This thesis will investigate two different countries' standards regarding electrical power systems and compare two grid designs in an off grid rural area. The aim is to show what differences the standards are creating and how they affect the design, structure and the economic requirements of grid development.

1.1 Background

A significant part of the world's population is living without any access to electricity. Whilst these people are struggling, richer countries are facing the challenge of replacing their existing energy sources into renewable ones, and an aging grid. To improve the access to electricity whilst fighting for renewable energy sources with a high demand for commercial efficiency, large investments in expansion and reconstruction of the existing electricity grids are required.

An alternative to expansion or reconstruction of the grids can be to start building islands of electricity grids, i.e. detached grids, here called micro grids, in small societies or villages. Micro grids eliminates long interconnections to the existing main grid infrastructure which are often causing instability in the grid. Furthermore, they could also increase the grid resilience compared to the traditional solutions, which is of great value in, for example, unstable countries where war or large uncertainty exists. Another advantage would be not having to clear forests or encumber fields in order to build right-of-ways to connect all the small villages to the main grid, and thereby decrease the impact on the nature or accessibility to natural resources.

To focus on a micro grid in a village or small town, and take advantage of the local resources, requires tailored solutions, adjusted for that specific society. Micro grids are suited to renewable solutions, which will reduce the need for large scale generation, typically based on fossil energy, nuclear power or hydro power, and it will reduce the need for transport of electricity.

ÅF is a company that has seen an increased demand of micro grids internationally, but also in Sweden, and therefore wants to acquire a comprehensive and solid view about them, commercially and technically. ÅF believes that current solutions for applying today's standards on power grid design may have serious consequences for micro grids. Differences in standards between countries can be large and building a micro grid in Sweden compared to in a developing country can be very different both economically and technically. Therefore, ÅF wants to attack this issue and investigate differences in standards and the consequences of these differences.

This thesis will focus on a set of standards and guidelines used when constructing a grid. Standards are of great importance and give the client and end user an insurance of functionality as well as increasing the possibility for integration of other systems. As an example, The National Institute of Standards and Technology has been working with development of standards for smart grids. The importance of this work has been brought up in America, as an example of bringing together manufactures, consumers, energy providers, and regulators, to work together, [1]. Another example are the grid codes by the European Network of Transmission System Operators for Electricity. The grid codes are developed guidelines and rules for network operators, generators, suppliers, and consumers which will enable effective operations across the market [2]. Both these examples emphasise the importance of standards, and why the lack of them may cause a divided and more narrow market which could be negative for all parties. Also, new technology requires that old standards are renewed so as to allow for full integration and utilisation.

1.2 Purpose and goal

The purpose with this thesis is to investigate the differences between international standards. The main aspects to investigate will be how the standards affect the basic structure of the grid and the cost of constructing the grid. The reason to do this is to get an understanding of the importance of standards and how they can affect the construction, stability and cost of a grid. This in turn will lead to a better knowledge of other countries' markets, and act as a bridge between the know-how of Sweden and different countries' requirements globally. In order to invest in a foreign country's business market, an understanding of why, how and what is of high importance, and thereby simplifies the road to future investments.

1.3 Implementation

The investigation will be made through an analysis of a micro grid constructed for a village or industry in Venezuela. The grid will be constructed in line with the Swedish standards and then with the Venezuelan standards. Several grid calculations will be made in order to ensure the functionality of the grid. When the grid is in line with each country's standards, or guidelines, and functionality demands, the structure and the purpose of the standards will be evaluated together with a cost calculation of each grid.

The grid calculations will be made in a grid calculation program, PowerFactory, provided by Lund University. A model of the grid will be constructed and several simulations will be made in order to provide the information needed for the necessary results. The simulations will show the electrical loading for each cable and related electrical infrastructure, the total grid losses, the voltage deviation and all short circuit currents.

The analysis will be made through implementation of two different load profiles, in two countries. The load profiles combined with the two countries create four different scenarios which will all be presented and discussed. For each scenario a grid will be built in PowerFactory. PowerFactory will provide everything needed in order to design the grid. When doing a cost calculation, a template provided by ÅF will be used in the Swedish scenarios. In the Venezuelan scenarios, a cost template is provided by contacts in Venezuela.

1.4 Limitations

The analysis is made from a technical and economic perspective, but not from a legal or regulatory perspective.

The chosen country Venezuela does not have easy access to well developed standards, and therefore, much knowledge has been given from employees at ÅF, who currently work in or have been working with power grids in the country. This will give guidelines on how and why the grids are built.

This thesis focuses on the standards regarding cable dimensions and cable structure in order to determine cost differentials between Swedish and Venezuelan standards. It will also consider the standard voltages, frequency and short circuit clearing time. Not all standards can be considered, due to lack of time. Whilst important, these have not been considered because they will not have none or limited effect on the built model in the thesis.

The location chosen for the development of a micro grid is unknown and no name of it or technical data about it has been found. Therefore, all data on energy consumption has been collected from other places or from hands-on experience from ÅF.

The net calculation program used in this thesis, PowerFactory, limits the grid to 50 nodes, which forces some of the loads in the simulation to be merged. Due to lack of time, this thesis only considers peak loads, showing the "worst case scenario" for each grid, and will not include hourly data regarding the energy consumption.

Chapter 2

Basic Grid Design

In this chapter, the basics of constructing a grid will be presented. There are several important steps and factors that need to be considered and followed. The following chapters in this thesis will go through those steps that are not already set, and in the end produce a grid for a chosen area.

2.1 Basics

First of all, when designing a grid, the area must be analysed together with the power demand. Basic things as the surroundings of the area, the nature, climate and resources need to be considered and evaluated. An important step is to investigate the energy demand of all consumers in the area. This could be houses, but also street lights and industries. The energy demand will play a crucial part in the design of the total grid, such as dimension of cables, transformers and possible generation solutions.

2.2 AC or DC?

Today, electricity grids consists of mostly alternating current (AC) systems feeding the end users, but lately, the question of why direct current (DC) is not used more has been brought up. The discussion between AC or DC systems began already in the 19^{th} century, during the "battle of the currents", between Thomas Alva Edison and George Westinghouse. Westinghouse, who worked with AC systems, won the fight at the time but as mentioned, there has been big discussions as to whether Westinghouse actually was the right winner or not for today's requirements [3]

The questions about DC distribution systems has recently been the topic in multiple reports and they show that a DC micro grid system offers several benefits compared to a conventional AC system [4].

Bosch developed a DC distributed micro grid with PV solar panels that showed that the reduction in conversion equipment made the system more efficient and reliable, as well as it reduced the installation and maintenance cost [5]. The DC design would eliminate the recurrent problem with frequency control and the fact that most equipment in our homes today are DC supplied is also a reason to rethink the use of DC. In India, they are currently working with 48 V DC systems in residential buildings because of the great fit with DC solar and battery systems [6].

Though the benefits of constructing a DC micro grid are plenty, there have not been enough studies on the subject and the development of standards for DC distributed grids has only just started. Therefore, the grid constructed in this thesis will be based on conventional AC grid solutions.

2.3 Micro grid

As mentioned in Chapter 1.1, the grid in this thesis will be a so called micro grid. The following definition of a micro grid is taken from the European Research Project [7]:

> "An interconnection of small, modular generation to low voltage distribution systems can form a new type of power system, the Micro Grid. Micro Grids can be connected to the main power network or be operated autonomously, similar to power systems of physical islands."

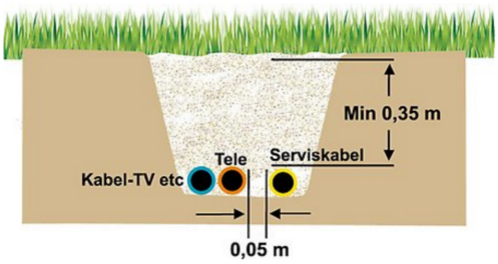
This means that a micro grid can be defined as a group of interconnected loads together with one or more distributed energy resource which acts as a single entity. The grid should be controllable and work within clearly defined electrical boundaries. The energy sources are preferably renewable sources like PV solar panels, wind or water energy, bio-gas or similar.

Building a micro grid is a way to incorporate renewable energy sources into the existing energy system but is also a way of enhancing reliability. From the customer's view the micro grid can reduce emissions by only using renewable energy sources, enhance local reliability by acting as an islanded grid, improve power quality by supporting voltage and reducing voltage drops, and potentially lower the costs of the energy supply. The micro grid is also a controlled entity within the power system that can act both as a load or as a generator and that is also able to support the utility grid, which benefits the grid operator [8].

The micro grid can, as mentioned, work both interconnected with the utility grid and disconnect itself when needed, but it can also be constructed to always work autonomously, in "islanded mode". The design for an islanded micro grid will be used when, for example, the area is located in a far distance from the utility grid or on an island, or when the terrain surrounding the area makes accessing difficult.

2.4 Layout of the grid

Before starting to dimension all components in the grid the layout of the grid need to be set, deciding which parts needs to be high voltage and low voltage and where they will go. Distribution stations, transformer stations and cable cabinets needs to be placed as well as all the cables. Things to consider is whether the grid will be buried or installed as overhead lines. In Sweden, most of all new built grids are buried through trenching and requires a lot of effort regarding placement of trenches. In some cases, the method of plowing is also used in order to bury the cables. In Figure 2.1, an example of a cable trench is shown, where electrical cables are buried together with telecommunication cables, and also an example of an overhead line in Sweden. The overhead line construction is cheaper than to bury the cables, not only because of the needed trenching but also because of the more advanced cable structure that is needed with ground cables, not being able to use the air as heat dissipating material. On the contrary, the overhead lines create issues of stability due to rough weather, safety and theft. Also, they take up a lot of space in the forests through their right-of-ways that needs to be free from any obstacles, for example trees. Many overhead lines are now replaced with buried cable, mainly in order to make the power transmission less exposed to severe weather.



(a) Cable trench, [9]

(b) An overhead line, [10]

Figure 2.1: Cable trenching or overhead lines.

Cable trenching needs to be planned in order to not make a too large impact, and a normal method is to lay the cables next to the roads, allowing easier access in case of repair or change of the cables. Another thing to take into consideration is that the excavation required for cable trenches is expensive, and therefore, the cables are often laid together, in parallel, as far as they can, in one cable trench, in order to minimise the costs. This also causes problems, since the cables cannot be too long in order to maintain quality of the supply, minimise losses usually occurring through heat transfer between cables, and voltage drops. Therefore, length needs to be considered, and thereby cable cabinets needs to be placed in strategic locations. It allows long cables to be shortened and thereby minimises losses. Addition of fuses results in better fuse trip times and also allows disconnections affecting easier fault detection. This is balanced by economy, cabinet costs and required maintenance. In Figure 2.2 the grid structure in a residential area is shown. From point 3, the transformer station, the voltage is transformed to the low voltage level, and then sent to a cable cabinet, point 4. Each house, point 5, is then connected to the cable cabinets. If there were no cable cabinets, the cables from the transformer stations would be very long, and the losses thereby much higher.

Figure 2.2: Grid structure in residential area. 1: Distribution station, 2: High voltage cable, 3: Transformer station, 4: Cable cabinet, 5: Connection to house, [11]

All this planning will cause questions about property ownerships and permissions, which also is a big part in grid design.

2.5 Dimensioning of the components in the grid

When deciding which size the components in the grid need to be there are several step to go trough. The transformers can be dimensioned by combining the total power needed in that part of the grid and also looking at voltage requirements, and economic requirements.

Choosing cable dimensions requires several steps, and the first one is calculation of load currents. Having decided the load to each customer, the peak and average power on each cable can be derived. The voltage target is normally set according to the standards of the corresponding country, and therefore the current on the cable can easily be calculated. The calculated current is the first indication of which size the cable needs to be and the cable needs to have a rated current (ampacity) higher than the maximum calculated current. The most common conducting materials are copper and aluminium. The electrical conductivity of copper is $6 * 10^7$ S/m and the conductivity for aluminium is $3.7 * 10^7$ S/m, [12]. Copper is a material that is relatively rare and except for its high conductivity, it has other beneficial qualities, for example, it is corrosion-resistant and wearable. Aluminium is lighter than copper and cheaper, but have slightly less conductivity. Because of its economic benefits, aluminium is often used as conducting material in cables. Below, in Figure 2.3, the cable structures of a copper and an aluminium cable are shown, [39]. The sizes in the picture have no relation to the real sizes.

(a) The structure of a copper cable, [39]

(b) The structure of an aluminium cable, [39]

Figure 2.3: Copper and aluminium cables, N1XV-U and N1XV-AS/AR.

Having the first iteration of components dimensioned, a suitable way to continue is through simulations of the grid. This would mean to build a model of the grid in a program and running simulations to test if the parameters will ensure grid functionality. Things to consider is the voltage to the end user, the electrical loading on the cables and other components, the losses, the short circuit currents and fuse trip time. The losses are in relation to the current in a cable, according to the power equation

2.1.

$$P = U * I = R * I^2 \tag{2.1}$$

There are several factors that decide if the grid is considered to be well designed and dimensioned properly. For example, the grid must function, all affected property owners need to be happy and the design has to be economically justified. Voltage to the end user has to be within the given limit, the electrical loading and losses should not be too large and the cables have to be dimensioned so that they can handle short circuit currents. Fuses are also very important as they will protect the electrical system, and will interrupt the fault currents that may occur. The voltage to the end user is important not only for the customer, who normally has no means to adjust the voltage received, but also for the grid owners who can use the voltage as an indicator for strong or weak parts of a network, [13].

Chapter 3

Case study

The selected location for development of this theoretical micro grid is Venezuela. In order to fully reflect the realities faced by many rural communities globally, a location far from civilisation has been chosen and as such the assumption of an interconnection to a main grid in the area has been eliminated. Therefore, the structure of a free standing or so called island micro grid is obtained. The principle of a micro grid can be used everywhere. Redundancy in this case is limited, and therefore, the energy consumption of the village will be divided into two different load profiles, one where the village reflects low consumption with only residential energy consumers, and another where the houses in the village are considered to be mixed with small industries or factories. This allows for the creation of four scenarios; two different countries with two different load profiles.

The country Venezuela was chosen due to its current energy situation. The country is known for its constant power outages, severe water crises, and a growing risk for conflict by people who now are used to a life with no light, [14], [15], [16]. It is a country in apparent decline in which standards have not been maintained and are currently unlike the Swedish standards, making the country a relevant participating choice for this investigation.

3.1 Geographical location

The chosen village is located in the western region of Venezuela, coordinates north 6.84°, west 68.92°. It is small, with 58 houses of different sizes. The houses are all centred around a larger set of houses, or barns, which could be some kind of farming facilities or small individual industries. The village's name is unknown, and therefore, no accurate measured data regarding number of inhabitants, their energy requirements and/or consumption has been found. The village is surrounded by some sparse forest, mostly small trees and bushes. It is plausible that this could be used for energy generation but this has not been investigated in order to analyse the requirements needed for a fully renewable system. Approximately 200 meters north of the centre of the village is a river, see Figure 3.1 and 3.2.

As can be seen in the pictures, a few small roads lead towards the village and some of the landscape located west of the village may be cultivated. This means easy access to the village for trucks or boats, with the purpose to build a grid.

Figure 3.1: The area surrounding the village, [17]

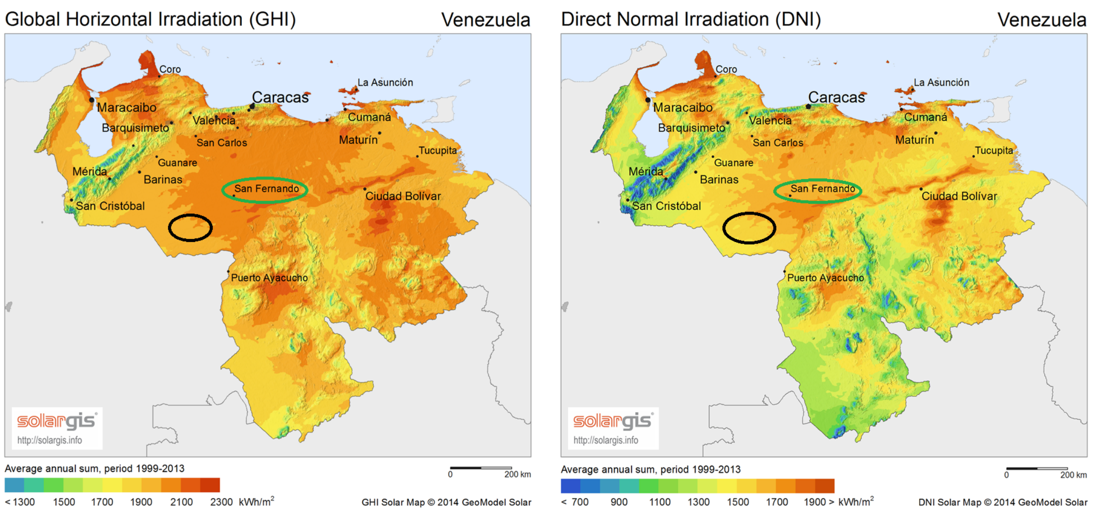
Figure 3.2: The village, [17]

3.2 Climate and resources

This section will present information about the climate and resources of the chosen location. It will clarify for some of the choices regarding renewable energy sources and their technology.

The village is located in the tropical zone of Venezuela, <800 meters above the sea level. Venezuela is located just above the equator, see Figure 3.3. The temperature is quite constant throughout the year, with a yearly average temperature ranging between 26-28°C, [18]. According to a climate report of the city San Fernando de Apure, which is one of the closest cities with a weather station, the mean number of hours of sun in the area is 2.779 hours per year [19], which is 30% of a year (8760 hours). This means that it is a location with good conditions for solar panels.

Figure 3.3: Venezuela and the equator, [21]



(a) Global horizontal irradiation. Black circle: location of the village. Green circle: Loaction of San Fernando de Apure, [19].

(b) Direct normal irradiation. Black circle: location of the village. Green circle: Loaction of San Fernando de Apure, [19].

Figure 3.4: Average annual irridiation, period 1999-2013

Based on the study in [22], the mean wind speed in the area, at 80 meters height above ground, is between 5-6 m/s, see Figure 3.5. The height 80 meters is chosen as a measure point since it is a normal height of where the wind turbines will produce around 1-3 MW (installed capacity), [23]. It is assumed that the tower has to be high enough for wind to not be disturbed by the nature or surroundings and it also has to be higher than the lengths of the rotor blades. The rotor blades may be around 60 meters, and therefore, the tower would be expected to be around 80-90 meters, [24].

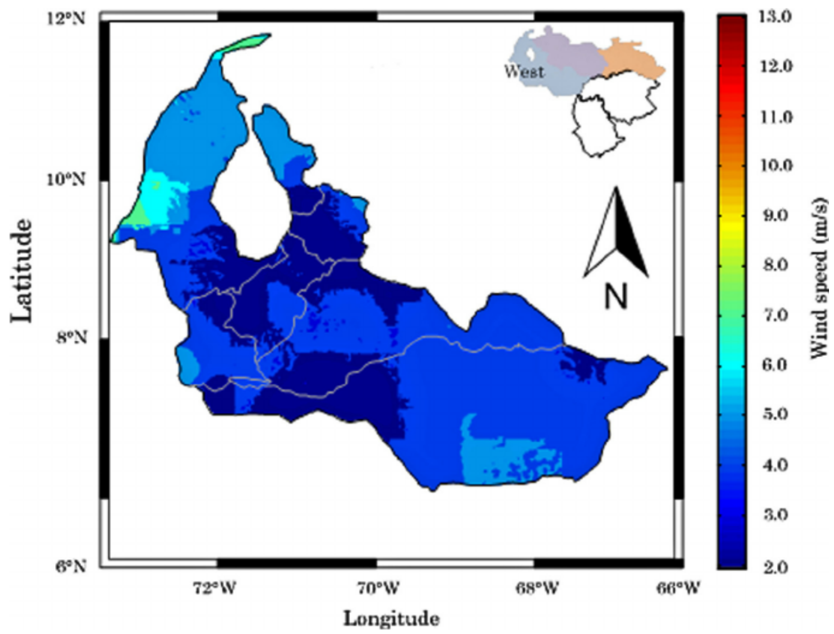


Figure 3.5: Wind speed at 80 m height, in the west region of Venezuela, [22]

The rain period in the area is during the high-sun month, i.e. during May - September. According to [26], see Figure 3.6, the average precipitation is around 200 mm during the rain period and 50 mm otherwise. The rain is important in this type of climate zone, where the temperature is constant and the risk of drought is high. The flow of the river is depending on the rainfall in the area and upstream rainfall. This is important in order to know if the technology of a hydro turbine solution would be possible. As for the moment, the country is in severe drought, and a hydro power turbine in the river would not be an option, but since the country has been heavily dependent on hydro power, [25], this solution will be discussed.

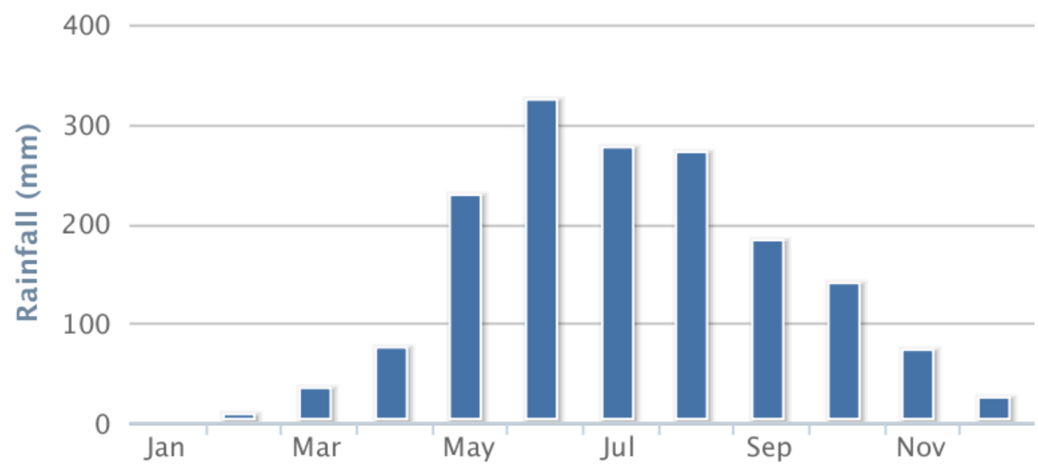


Figure 3.6: Average monthly rainfall in the village, [26]

The river is approximately 144 meters wide and the depth of it is about 10 meters, see Figure 3.7 and 3.8. The height is measured by the bottom of the river, as meters over the sea level. The figure shows an elevation of approximately 10 meters (i.e the depth of the river) which could be used as a base for a hydro electric generation. The water current velocity in the river is unknown.

Figure 3.7: Distance across the river, [17]

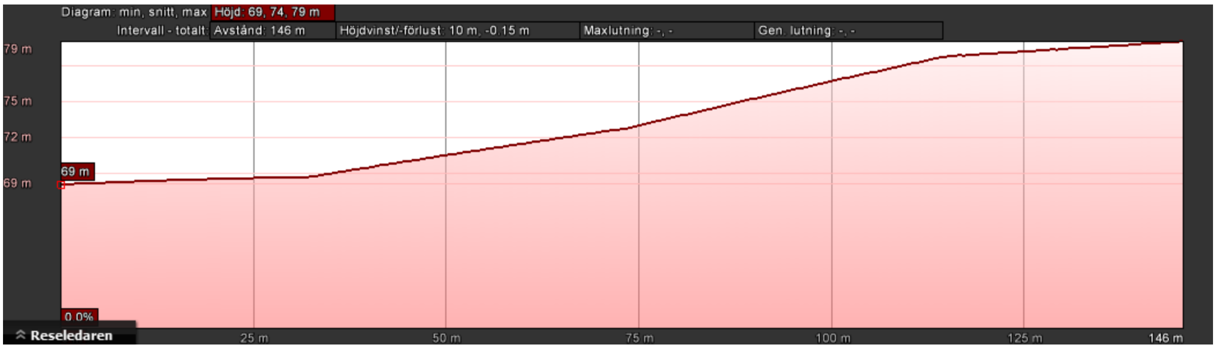


Figure 3.8: The difference in height across the river, [17]

3.3 Energy demand

Two different load profiles have been applied in two different countries, Sweden and Venezuela, in order to compare the associated economic requirements and to see which factors within the project affect the cost prognosis the most, confined of course by the scope of this report.

Load profile "Mini":

In the first profile, the houses are considered as residential homes. Since no measured data regarding the village was found, measurements from another location was used. An American website with open data sets, [27], presents hourly measured power consumption for different appliances in residential buildings all over USA. The chosen measurements were from a building in Bronxville, Texas, as this location was the southernmost located city in the list, and therefore the city with the most similar climate as the chosen location in Venezuela. The data was presented in a file with power consumption for each hour during a year, in this case year 2014. In Table 3.1, the different appliances for which the energy is measured are presented. In order to adjust the energy consumption to each type of facility in the village, the facilities were categorised, depending on their size on the map, as 4 Large houses, 6 Medium houses and 48 Small houses and they were all given appliances as seen in Table 3.1 below. For example, the small houses act as the base case, with a base load profile. They only have energy needed to supply the house, eg. fans, lights and appliances inside the house and a water heater. They are set to not be needing electrical heating, since the climate is warm and constant throughout the year, see Section 3.2. This categorisation of measurements is set in order to specify the different facilities and in order to get a "worst case" scenario for the simulations.

Table 3.1: Houses and their energy factors, Load profile 1

Measurement	Large - 4 houses	Medium - 6 houses	Small - 48 houses
Electricity:Facility	x	x	x
Heating:Electricity	x		
Cooling:Electricity	x		
Electricity:HVAC	x	x	
Fans:Electricity	x	x	x
General:InteriorLights:Electricity	x	x	x
Appliances:InteriorEquip:Elec.	x	x	x
Miscellaneous:InteriorEquip:Elec.	x	x	
WaterHeater:WaterSystems:Elec.	x	x	x

From the categorisation of the facilities, the total energy consumption of all houses were summarised, hour for hour, and the result is seen in Figure 3.9. A few power peaks can be seen and they are all due to a combination of increased usage of Electricity:Facility, Heating:Electricity and WaterHeater:WaterSystems:Elec. in the morning, around 07.00-8.00. The red circle shows the hour with the highest power consumption of the village: 07:00-08:00 on the 20th of January. During this hour, the total energy consumption of the village is approximately 412 kWh, and the power consumption of a large house during this hour is 13.4 kW, a medium house consumes 10.1 kW and a small house consumes 6.2 kW, as seen in Table 3.2. This data is later used when designing and building the simulation model, in Chapter 5. The curve seen in Figure 3.9, indicating a higher energy consumption during the summer months, could be explained by the use of fans and cooling systems during the warmer summer months, but since the climate is relatively unchanging throughout the year in Venezuela, this variation is not big.

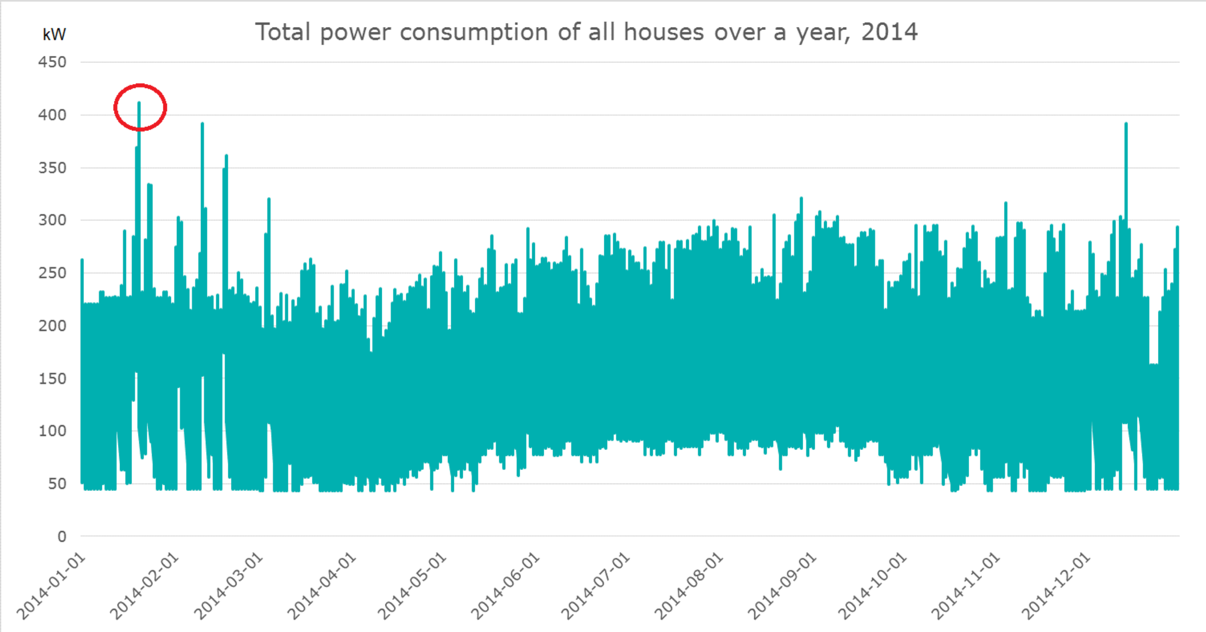
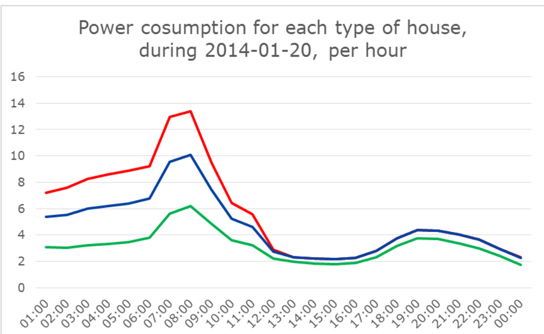


Figure 3.9: Power consumption for all 58 houses over a year, 2014, Load profile 1

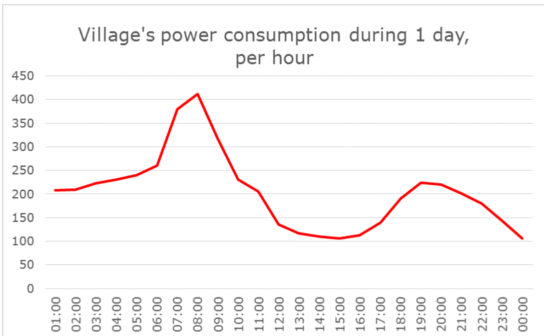
Table 3.2: Power demand, load profile 1

House type	kW/house	Number of houses	Total power [kW]
Large	13.4	4	53.9
Medium	10.1	6	60.6
Small	6.2	48	297.6
All houses:	-	**58**	**411.8**

In Figure 3.10, the power consumption for each type of house during the "worst case"-day is shown (20th of January), and also the village's total energy consumption during this day. The total power consumption is used in order to propose different generation possibilities, see Chapter 5.



(a) Each type of house during 1 day.
Green: Small, Blue: Medium, Red: Large



(b) The village during 1 day

Figure 3.10: Load profile 1, power consumption based on the day with the worst case hour, January 20th, see Table 3.2

Load profile "Large":

Here, the energy consumption is larger. Some of the buildings are considered to be small individual industries or factories, and some are considered as residential houses with a small daily energy consumption. This load profile has has been developed using the experience of staff at ÅF.

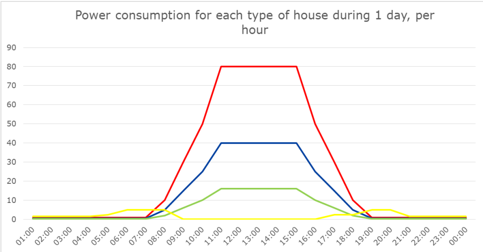
The buildings are divided into 4 categories, depending on their size on the map; 4 Large, 4 Medium, 2 Small and 48 Extra Small. The large buildings have a peak load of 100 kW, the medium buildings 50 kW, the small buildings 20kW and the extra small buildings, 5 kW. The power consumption over a day is seen in Figure 3.11a. Here it is seen that the large, medium and small buildings are all using more power during the middle of the day, since they are said to be factories or industries. The extra small houses (yellow line) are residential and are using more power in the morning and in the evening. These extra small houses can be compared with the small houses in Load Profile "Mini". As seen in Section 3.3, the load profile for the small houses also have a peak in the morning and in the afternoon.

In the simulations made for this load profile, the peak loads that will be used are shown in Table 3.3. In Figure 3.11b, the total power consumption of the village during one day is shown and this is used later in Chapter 5, when discussing the generation possibilities.

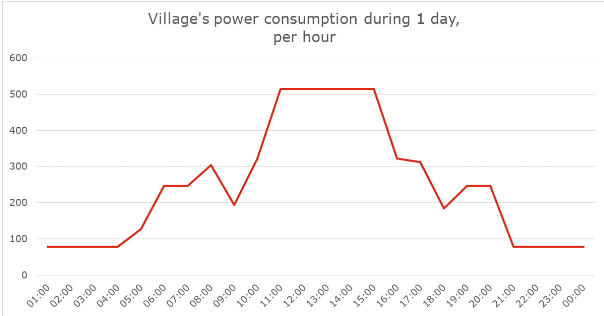
Table 3.3: Power demand, load profile 2

House type	kW/house	Number of houses	Total power [kW]
Large	100	4	400
Medium	50	4	200
Small	20	2	40
Extra Small	5	48	240
All houses:	-	**58**	**880**

In the following figures, the load profile is not derived from real energy consumption data, and therefore no date is given. The first figure shows the energy consumption for each type of house during one day. The second figure shows the power consumption of the whole village together, during the same day as Figure 3.11a.



(a) Each type of house during 1 day
Yellow: Extra small, Green: Small, Blue: Medium, Red: Large



(b) The village's power consumption during 1 day

Figure 3.11: Load profile 2, power consumption based on given load profile in Table 3.3

Chapter 4

Standards and guidelines

When constructing a grid, isolated or interconnected, each country's standards and guidelines need to be applied. The standards are important to apply, and in Sweden they are used as an assurance of quality and safety as well as they ease the design and construction choices. They will also assure the inter-connectivity to other equipment.

In this chapter, the standards regarding voltage levels, frequency, short circuits and cable design for Sweden and for Venezuela will be discussed. In order to narrow down the different areas involved, the focus is set on construction of the grid. This chapter will present a summary of the Swedish standards found in Appendix A and the Venezuelan standards found in Appendix B.

4.1 Sweden

Sweden has developed a series of standards covering all areas of planning, constructing and utilisation of a grid. The standards can be found individually on the website of the Swedish Electrical Standards, [28]. They are also interpreted, commented and used in books as, for example, the book of high voltages, SEK Handbok 438 [29]. The book is based on the standard SS 421 01 01 and is a guide to high voltage grids.

One must consider several things when designing a power system. First, the rated voltage in a Swedish distribution grid is set to be AC low voltage 230/400 V, or medium voltage 6-24 kV. Impedances in the grid will cause voltage drop but the construction must not give excessive voltage variations. The acceptable limit for this is ±10% of the rated voltage U_n, but when a system is isolated this limit can be stretched up to $+10/-15\%$, see Appendix A.3.

The frequency of the Swedish grid is 50 Hz, and is constantly controlled in order to keep the frequency stable. According to the standards, the frequency for a system synchronously connected to the main power system can vary between 49.5-50.5 Hz during 99.5% of a year. For a system without a synchronous connection to a main system, as an islanded micro grid, the frequency is allowed to vary between 49-51 Hz during 95% of a week.

All loads must be considered and in order to obtain an economic and reliable embodiment of a system, the maximum load capacity needs to be calculated. This can be done considering the combined power, using, for example, Velander's method or formula which is used to estimate peak load from the annual energy consumption, [30].

When starting to design the system and the cables, the expected load applied to the cable during normal operation has to be calculated, in order to dimension the cable so as to fulfil the requirements set by the standards. All cables are designed with a specific rated current (ampacity), for which the load during normal operation is not allowed to exceed. Examples of these currents for can be seen in Appendix A.6. The values reflect cable design solutions when the cable is laid directly in ground. Due to serious storms and supply disruption, this is now the normal way to develop grids in Sweden. In Sweden, copper is used as a conductor material for cables with a cross section area up to 16 mm^2. For larger cable areas, aluminium is used. Also, the most common insulation material is cross linked polyethylene, which has a maximum operating temperature of 90°C, compared to the material polyvinyl chloride which has a maximum operating temperature of 70°C. The standards also show the resistance of the cables, as for an aluminium conductor with cross-section area 95 mm^2, the resistance 0.32 Ω/km. For more examples, see Appendix A.7.

When the first design of the system is done, all short circuit current in the cables need to be calculated. When doing this, the fault clearing time of 0.1 s is used for a system with phase to phase voltage up to 400 V. For example, the maximum short circuit current for a 10 mm^2 copper conductor with the temperature of 90°C would be 1430 A. More examples of maximum short circuit currents can be found in Figure A.3.

In Sweden, a large factor of the electrical grid design and development concerns the safety of people and protection of the surroundings and equipment. Therefore, the system needs to be protected against high temperatures from resistive losses related to over currents and fault currents. This protection can be achieved by installing automatic disconnection of the over current or to limit the maximum over current value to a safe value. The electrical isolation and the surroundings of the cables are also of great importance as protection. For example, overhead cables will not be isolated by the soil, and therefore the air can lead away the heat easier. Cables in ground will be isolated by the soil, and therefore, they will have to be constructed and dimensioned in an other way in order to cope with the remaining heat.

When designing an electrical grid, many things are left to the designer to decide. The cables used are often chosen by requirements of electrical companies based both on electrical requirements but also on agreements with suppliers. In Chapter 5, the grids in this thesis are designed and motivations about the choices will be presented in that chapter.

4.2 Venezuela

The Venezuelan standards are assembled in the "Código Eléctrico Normal", [32]. Though, this assembly does not include specific details about cable sizes and voltage variations, some guidelines towards calculations and how to extract information can be found, see Appendix B. The document is said to serve as a manual or design specification for untrained personnel, and as stated by staff at ÅF, [33], most of the knowledge is obtained by experience.

The frequency used in Venezuela is 60 Hz, and the rated voltage is depending on the class of tension, 120/240 V, 277/480 V, 600 V etc. In order to maintain stability and safety of the system in Venezuela, it is normal to dimension the system as 25 % larger, and therefore, when calculating the currents during normal circumstances, it is multiplied with a factor 1.25. This is both for low voltage systems and high voltage systems. There is no limit of voltage deviation, but it is stated that the voltage may vary within a band that allows the functionality of the equipment. An appropriate solution could be to use the corresponding standards used in USA, since Venezuela is using similar voltage levels (120 V phase to phase, [34]) and also the same frequency (60 Hz). In this thesis though, the Swedish limits will be used for the Venezuelan cables as well.

The system shall also be protected with over current protection. The required short-circuit protections are considered to be met if the fuse's continuous value of its rated capacity is no more than three times the current capacity of the conductor, i.e. the fuse will break when the current through it reaches three times the current capacity in the conductor. The protection is also considered met if the allowed current in the circuit breaker is six times higher than the current capacity of the conductor. This is only standards regarding the protection devices and no information about the maximum allowed current in the cables has been found.

In Venezuela, the cables are categorised with the American Wire Gage system, AWG. The minimum AWG size for copper is 8 AWG and for aluminium it is 6 AWG. The most normal conductor material used is copper. As seen in Table B.1, the minimum size of conductors with the system voltage up to 2 kV is 14 AWG. It is stated that the temperature is not allowed to exceed the given limit for the operating temperature of the conductor. Below in Table 4.1, a comparison between the system AWG and their conductor area in mm^2 is shown.

AWG	**mm^2**
14	2.08
10	5.26
6	13.3
2	33.3
1/0	53.5
2/0	67.4
3/0	85
500	253
700	380

Table 4.1: AWG to area, mm^2, for low voltage cables, [35]

There are not many detailed standards in the "Código Eléctrico Normal". Most of them are applied to special cases and equipment. In order to continue with the assignment of finding standards for grid construction, information has been given by ÅF:

- The nominal grid frequency if 60 Hz. This can be read in the "Códe Eléctrico Normal" but is not stated as a standard.
- The rated voltage in this type of grid should be 120/240 V (phase voltage/main voltage) for the distribution part and 10 kV for the high-voltage part of the grid, as these are the most common voltage levels.
- The voltage actually used in the grid should be 127/220 V (phase voltage/main voltage).
- Bases on design experience, a power factor of 0.8-0.85 is used depending on type of end consumer (house of industry).
- The maximum operating temperature of the cables and most of the other equipment is 60-70 °C, but is depending on the manufacturer. As for the cables used, the maximum operating temperature is 90 °C.
- The most common cable manufacture is General Cable and the type of cable mostly used is the Superflex Multiconductor 3-phases with a cable size from 14 AWG to 750 AWG. [35]

More details about guidelines and the chosen cables etc can be found in Chapter 5, where the grid will be constructed.

Chapter 5

Grid design

In this chapter, the grid will be designed. First, the base model of the grid will be presented, in order to see the structure and the choices that has been made. An overview of the area, the total structure of the grid and the energy generation choices are presented. Also, the cable dimension calculations and the steps through the design of the simulation model will be explained. In Section 5.2 and 5.3, the specifics of each country's grid model are presented, including cable dimensions and parameters of other components, as transformers. As previously mentioned, there are a total of four scenarios: Sweden Mini, Sweden Large, Venezuela Mini and Venezuela Large. These scenarios are chosen not only to compare the standards in the two countries but also to see which economic factors that affects the cost prognosis the most.

5.1 The base grid

Assuming the village has generation capacity, the scope of this thesis is to design an electrical grid capable of fulfilling Swedish standards and then compare the Swedish solution with the Venezuelan solution in order to see the differences between the standards and how they affect the system, both technically and an economically.

Overview

In figure 5.1 the base structure of the grid in presented. It was drawn in Google Earth, [17] and the distances of the cables were also measured in the program. Most of the cables are placed along the roads in the village.

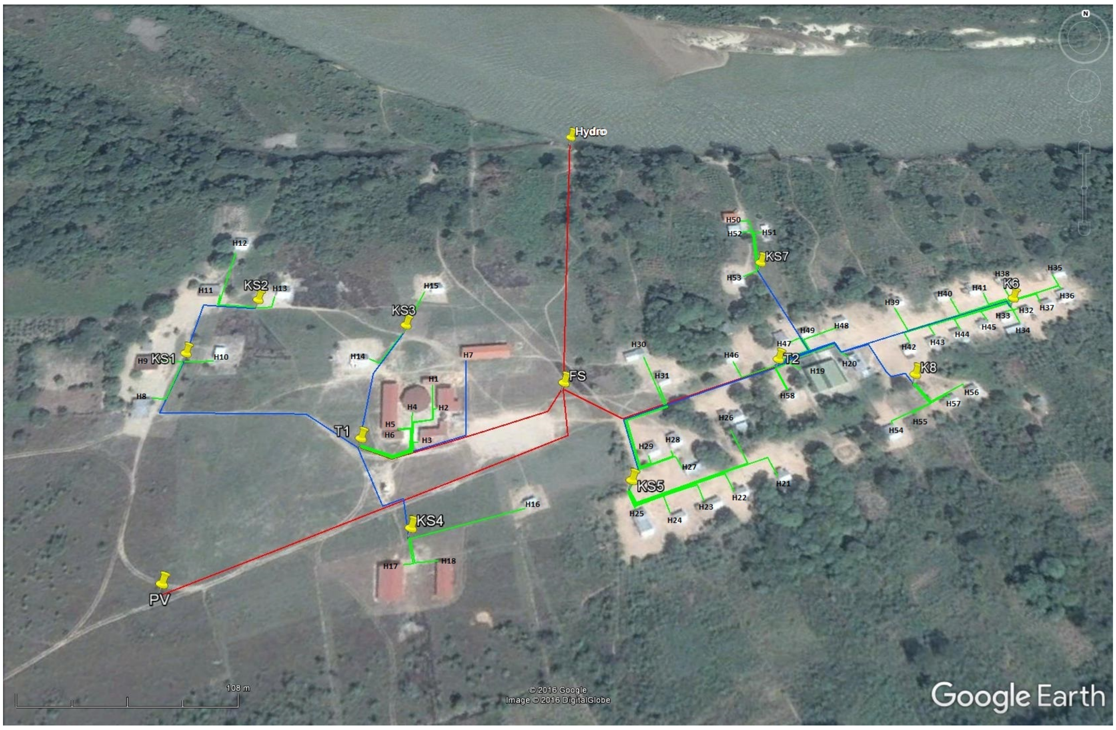


Figure 5.1: The base structure of the grid with the houses, [17]

The red lines marks the high voltage grid going from the power generation to a distribution station, called FS, and then further to two transformer stations, T1 and T2. The power generation systems are here chosen to be one PV solar plant which would be placed at the spot "PV" and one, or several, hydro kinetic turbines in the river at the spot "Hydro". This will be discussed later on, when dimensioning the system. At the transformer stations, the voltage will be transformed from high voltage to low voltage, and then be distributed to the different cable cabinets and further on to the end users.

Electricity generation

The electricity generation will be included in the simulation model, only supplying the simulation scenarios, but a dimension of the generators will be discussed in this section. This because the simulations in PowerFactory will only be made with a fixed value on each load, and not with hourly numbers, but a dimension of the generators/plants are still interesting to do in order to understand the whole structure of the grid.

As mentioned in Chapter 3, the energy demand of the village has been divided in to two different load profiles. Scenario 1 and 3 will have load profile "Mini" and scenario 2 and 4 will have load profile "Large". When simulating the grid, the cables have been dimensioned for the "worst case scenario", i.e. maximum peak load. No consideration has been taken to Velander's method, where the interleave of the loads are calculated, see Chapter 4.1. In the Tables 3.2 and 3.3 in Chapter 3.3, all loads used when dimensioning the grid are listed.

Also in Chapter 3, Section 3.3, the two graphs of the village's total electricity consumption during one day are presented, one for each load profile. In load profile "Mini", the village's total energy consumption is 4 900 kWh/day and in load profile "Large", the energy consumption is 5 950 kWh/day. The chosen generation technologies in this thesis are PV solar panels and river hydro kinetic energy due to the excellent solar conditions and the nearby river. These technologies can be combined in different ways. The main generation will be from the solar panels, and it will be backed-up with one, or several, hydro kinetic turbine. Since there is no knowledge about the river's water current velocity, the assumption of perfect conditions for river turbines is made.

Load profile "Mini": The energy consumed during one day is 4 900 kWh. Due to lack of sun some days, a battery being able to store one day of energy is considered (4 900 kWh). Since the country (Venezuela) is located very close to the equator, see Figure 3.3 in Chapter 3.2, the assumption that the sun is up for 12 hours every day can can be made, and that the solar panels can work effectively during all 12 hours. If needing to generate enough energy to supply the village for one day and also at the same time charge the battery, in 12 hours, the installed capacity of the solar panels would need to be 816 kW, see Equation 5.1.

$$\frac{4900kWh * 2}{12h} = 816kW \tag{5.1}$$

If each panel would have capacity of 300 W, approximately 2 722 panels would be needed.

If combining the solar panels with hydro kinetic turbines, with the capacity of 100 kW, [36], [37], running 24 hours/day, assuming a constant flow of the river and perfect conditions for the turbine, the installed capacity of solar panels would be 617 kW, Equation 5.2. This is with the same assumptions as in the previous example (12 hours of sun, 1 day's capacity in storage).

$$\frac{(4900kWh * 2) - 100kW * 24h}{12h} = 617kW \tag{5.2}$$

It would mean a total of 2 056 panels with 300 W installed capacity each.

Load profile "Large": With the same assumption as in load profile "Mini", (12 hours of sun and 1 day's capacity in storage), the total solar capacity installed would need to be 992 kW, Equation 5.3.

$$\frac{5950kWh * 2}{12h} = 992kW \tag{5.3}$$

This would mean a total of 3 306 panels with an installed capacity of 300 W, and if adding 100 kW of installed hydro capacity the installed capacity of solar panels would only be 792 kW, supplying the village with load profile "Large" for two days, Equation 5.4.

$$\frac{(5950kWh*2)-100kW*24h}{12h}=792kW \tag{5.4}$$

Total number of solar panels with installed capacity of 300 W would be 2 639.

In Table 5.1, a summation of these different generation possibilities is shown in order to get an overview of the scenarios. The energy in kWh is the total amount of energy needed for two days, and the power of solar panels and hydro power is the installed capacity that would be needed if the panels could work for 12 hours per day and the hydro turbine 24 hours per day.

Table 5.1: The different load profiles and the two different generation solutions; only solar panels or combined with hydro power

Load profile	**Energy [kWh]**	**Solar panels [kW]**	**Hydro power [kW]**	**Nbr of panels à 300 W**
Mini	9 800	816	0	2 722
Mini	9 800	617	100	2 056
Large	11 900	992	0	3 306
Large	11 900	792	100	2 622

Cables

In order to dimension the cables for each scenario, all currents needed to be calculated, using Equation 5.5.

$$I=\frac{S}{\sqrt(3)*U_h}, \tag{5.5}$$

where S is the apparent power:

$$S=\frac{P}{cos(\phi)}, \tag{5.6}$$

P is the active power and ϕ is the power factor, here chosen to be 0.85 for all scenarios, as stated in the standards, see Chapter 4. All current calculations can be found in Appendix C and an example of one of the calculation can be found in Figure 5.2. The figure shows the cables from one station to another, the facility size that the cable is connected to and the measured length of the cable. It also shows the needed length, with an extra 3% because the cables are not stretched and another 10 meters for connection in each end, the transferred power in kW and kVA, the calculated current, and finally the proposed cable type. This example shows the Swedish cables for the Large load scenario (load profile

2).

Voltage	From	To	Type	Length [m]	Real length [+10 m+3%]	[kW]	[kVA]	Current [A]	Cable [mm^2]
10000	PV	FS	-	257	275	300	352,9	20,4	AXCEL 3*95
10000	Hydro	FS	-	192	208,1	580	682,4	39,4	AXCEL 3*95
10000	FS	T1	-	128	142,1	570	670,6	38,7	AXCEL 3*95
10000	FS	T2	-	134	148,3	310	364,7	21,1	AXCEL 3*95
400	T1	H1	M	83	95,8	50	58,8	84,9	N1XE-A4x95
400	KS1	H10	XS	17,5	28,3	5	5,9	8,5	N1XE-U5x10
400	KS2	H11	XS	31	42,2	5	5,9	8,5	N1XE-U5x10
400	KS2	H12	XS	62	74,2	5	5,9	8,5	N1XE-U5x10
400	KS2	H13	XS	17,5	28,3	5	5,9	8,5	N1XE-U5x10
400	KS3	H14	XS	30	41,2	5	5,9	8,5	N1XE-U5x10
400	KS3	H15	S	62	74,2	20	23,5	34	N1XE-U5x10
400	T1	KS1	-	155	170	30	35,3	50,9	N1XE-A4x95

Figure 5.2: Example of current calculation, Swedish Large grid

Simulation model

To build a simulation model, the program PowerFactory, provided by the division IEA, Industrial Electrical Engineering and Automation, at Lund University, was used. The model was built in the same way for all scenarios and is shown in Figures 5.3 and 5.4. The model is divided into three parts; high voltage, low voltage after transformer 1 and low voltage after transformer 2. The different voltages on the bus bars for each country is also shown in the figures. For each load profile, the end loads were changed, as were the cable dimensions, size of the transformers and the generation. In the model, the power generation from the PV model and the hydro kinetic turbine is only set to the instant power demand from the worst case hour, see Chapter 3. The real PV solar system and the hydro kinetic turbine would be much larger in order to supply the village for a whole day, or if some storage system was incorporated, several days.

As seen in the pictures, the model incorporates bus bars in every connection point. The bars represent each substation, but also each connection point, as the connection to and from the transformers, or to the loads etc. The program, PowerFactory, and the licence used, limits the number of bus bars to 50, and therefore, the end loads (houses) had to be merged in small groups of two, three or four houses. The peak loads were added up in each group and the longest distance in the group was used. The currents on each cable in the group were also summarised and the final cable in the model is dimensioned after this summarised current. In all the simulated grids, the hydro power generator is used as slack bus.

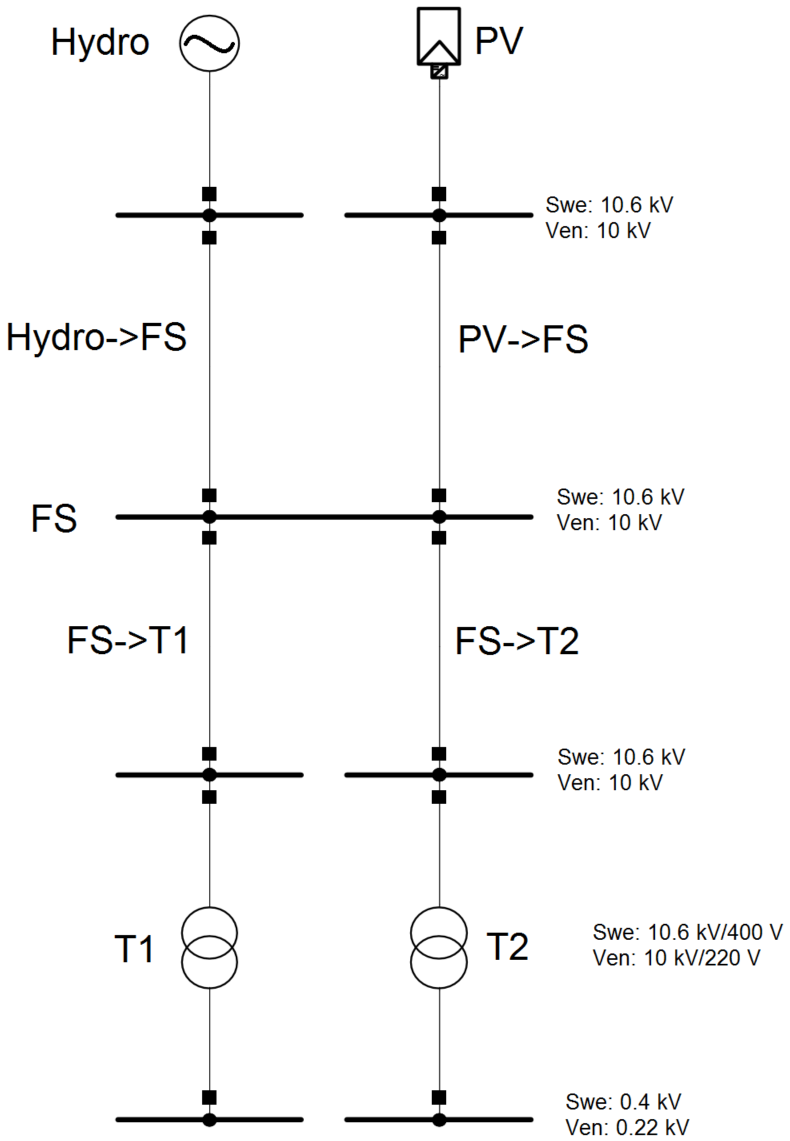
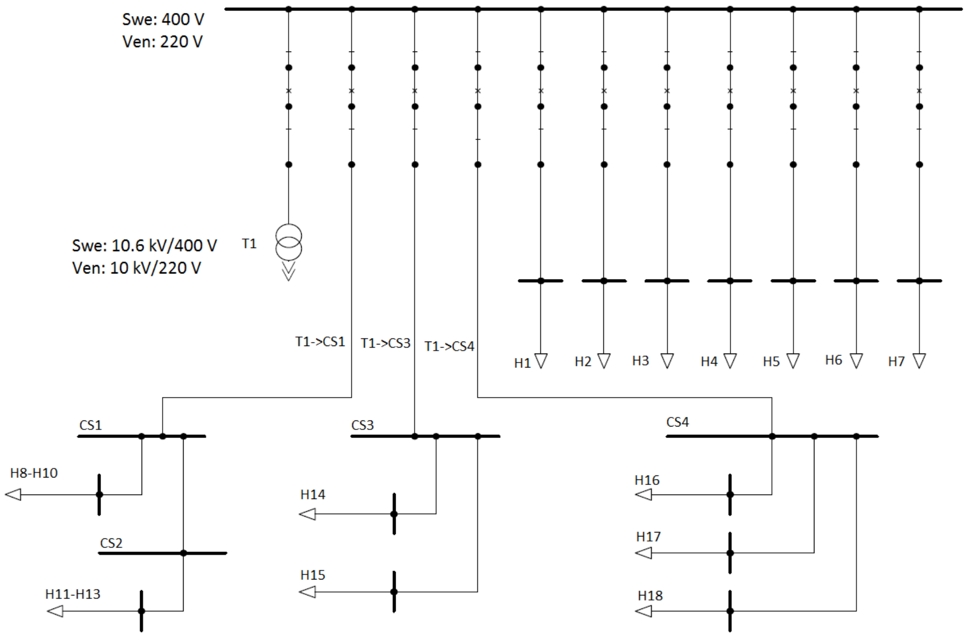
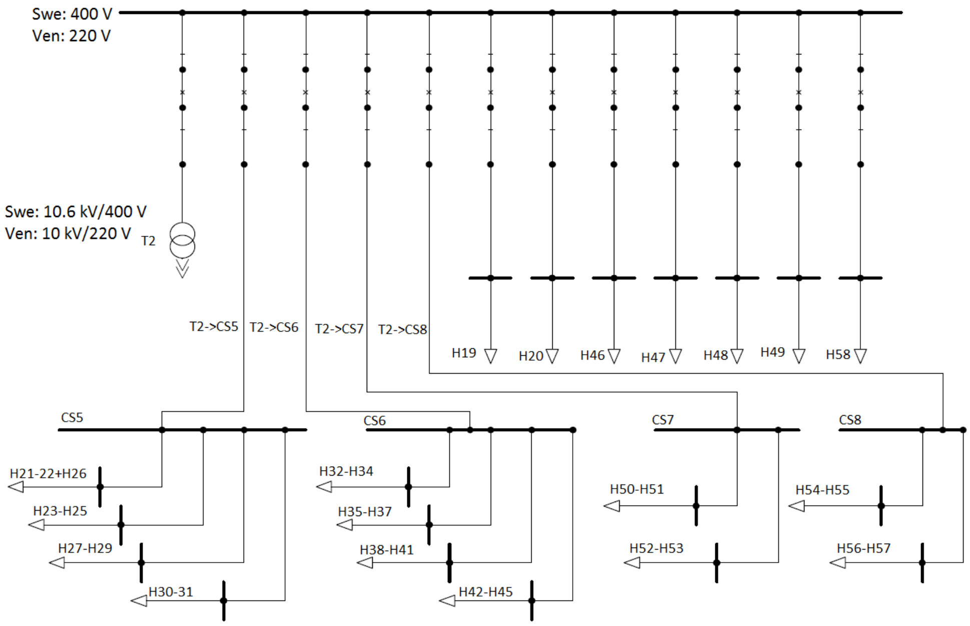


Figure 5.3: Simulation model part 1, High voltage



(a) After transformer 1



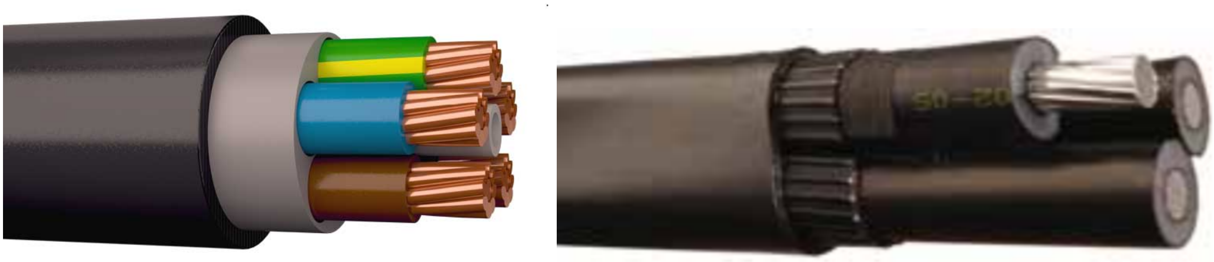
(b) After transformer 2

Figure 5.4: Simulation model part 2 and 3, low voltage

5.2 The Swedish models: Scenario 1 and 2

The Swedish model is based on the Swedish electricity standards, but also on requirements of electrical companies, based on both electrical requirements but also on agreements with suppliers.

The Swedish cables can for example be found in [39]. Commonly used cables are the N1XE cables for voltages of up to 1 kV and the AXCEL cables for 12 and 24 kV, triple core, see Figure 5.5.



(a) N1XE cable, [38]

(b) AXCEL cable, [39]

Figure 5.5: Cable structure of low and high voltage cable used.

The following Tables 5.2 and 5.3 will list all cables used for both the large and the mini grid and their specifics, found in different cable books and standards, see Appendix A, [39], [40]. The rated current (ampacity) of each cable is the manufacturer's limit of the maximum allowed current during normal operation. Common in Sweden is to use an even lower current, for example, the N1Xe-U5x10 cable has a rated current of 63 A, but for many grid companies, the limit is set to 50 A.

The chosen cable types and sizes for the simulations are presented in Appendix C.

Table 5.2: Swedish cables used and some of their specifics

Cable	**Area**	**Material**	**Isolation**	**Isolation**	**Temp**	**Rated current**
type	mm^2	*type*	*type*	*mm*	$^\circ C$	*A*
N1XE-U5x10	10	Cu	PEX	0,7	90	63
N1XE-U5x16	16	Cu	PEX	0,7	90	82
N1XE-A4x50	50	Al	PEX	1	90	116
N1XE-A4x95	95	Al	PEX	1,1	90	170
N1XE-A4x240	240	Al	PEX	1,7	90	286
AXCEL 3x50	50	Al	PEX	16	90	200
AXCEL 3x95	95	Al	PEX	19	90	295
AXCEL 3x240	240	Al	PEX	26	90	465

Table 5.3: Swedish cables used and some of their specifics

Cable	**Area**	**Resistance**	**Ø**	**S-C current**	**Inductance**	**Capacitance**
type	mm^2	*Ω/km*	*mm*	*A*	*mH/km*	*μF/km*
N1XE-U5x10	10	1,83	4,8	1 430	-	-
N1XE-U5x16	16	1,15	4,8	2 290	-	-
N1XE-A4x50	50	0,641	7,9	4 720	-	-
N1XE-A4x95	95	0,32	-	8 980	-	-
N1XE-A4x240	240	0,125	-	22 700	-	-
AXCEL 3x50	50	0,641	8	4 720	0,34	0,23
AXCEL 3x95	95	0,32	11,2	8 980	0,31	0,3
AXCEL 3x240	240	0,125	18	22 700	0,27	0,42

In order to get the right cable specifics in the simulation program, cables in the program library, "IEC Standard Cables", were used as base cables. The specific parameters for each cable, given from the producers, were then changed in order to simulate the right cable.

When dimensioning the system there were several standards and guidelines to take into consideration. They are all mentioned in Chapter 4. The limit of the voltage deviation to an end user is, according to the standards, +10/-15%. According to other guidelines used in Sweden, the limits used when designing the grid is +6/-10%, in order to ensure the quality of supply and increase end user satisfaction. In the two simulation models, the voltage limits are therefore set to be +6/-10%.

The frequency is, as mentioned in Chapter 4, 50 Hz, and the voltages are 10,6 kV (high/medium voltage) and 0,4 kV (low voltage). In order to supply the customers with the right voltage, the electrical companies in Sweden often step down their transformers so that the voltage on the low voltage side is a bit higher than nominal, about 2-3% higher. Instead of the phase voltage being 230 V, it can be set to 235 V. This is to ensure a better voltage quality to the customers.

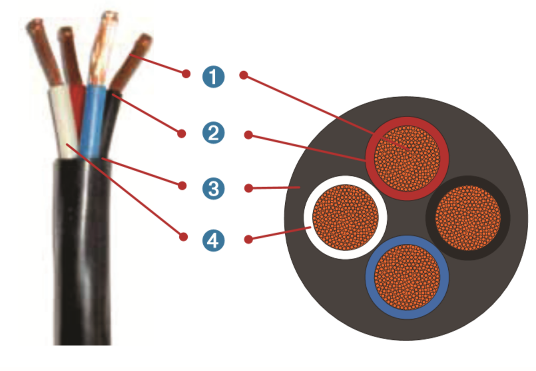
The transformers in the models are chosen to fit each system and normal practice for economic solutions. In the Large Grid, T1 (transformer 1) is a 800 kVA transformer and T2 (transformer 2) is a 500 kVA transformer. T1 in the Mini Grid is a 315 kVA transformer and T2 is a 500 kVA transformer. The difference between the grid from transformer number two in the two grids (Mini and Large) is not big, the difference in loads are placed after transformer 1, and therefore, the same size of transformer 2 can be used.

Table 5.4: The transformers in the Swedish grids

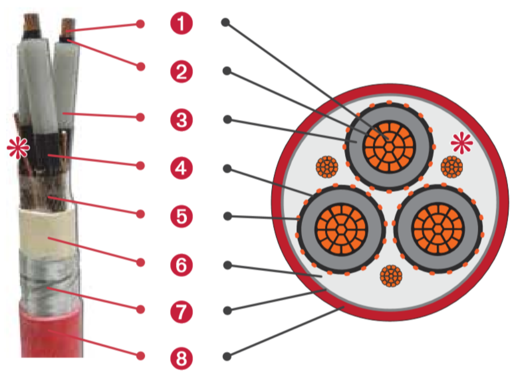
Grid	T1 [kVA]	T2 [kVA]
Large Grid	800	500
Mini Grid	315	500

5.3 The Venezuelan models: Scenario 3 and 4

The cables in Venezuela are copper cables, and the cables in Table 5.5 have been used in the simulations for both the Mini grid and the Large grid, and are from the cable producer General Cables, [35], see Figure 5.6. The first nine cables (14 to 750 AWG) are made for voltage up to 1 kV and the other three (2, 1, 1/0) are made for voltage up to 15 kV.



(a) Low voltage cable, structure



(b) High voltage cable, structure

Figure 5.6: Cable structure of low and high voltage cable used, [35].

Table 5.5: Venezuelan cables used and their specifics

AWG	**Area**	**Material**	**Isol.**	**Isol.**	**Temp**	**Rated current**	**Resistance**	**SC-current**
type	mm^2	*type*	*type*	*mm*	$^\circ C$	*A*	Ω/km	*A*
14	2,08	Cu	PEX	0,7	90	35	8,59	1 430
10	5,26	Cu	PEX	0,7	90	56	3,41	1 430
6	13,3	Cu	PEX	0,7	90	106	1,37	2 290
2	33,3	Cu	PEX	0,0	90	178	0,54	8 980
1/0	53,5	Cu	PEX	1,1	90	229	0,34	14 200
2/0	67,4	Cu	PEX	1,1	90	260	0,27	14 200
3/0	85	Cu	PEX	1,1	90	297	0,22	22 700
500	253	Cu	PEX	1,7	90	531	0,07	22 700
750	380	Cu	PEX	2	90	648	0,05	22 700
2	33,6	Cu	PEX	4,45	90	185	0,53	4 720
1	42,4	Cu	PEX	4,45	90	210	0,42	4 720
1/0	53,5	Cu	PEX	4,45	90	240	0,34	4 720

The Venezuelan model is built with a 10 kV high voltage grid and a 0,22 kV low voltage grid. According to the Venezuelan standards, the voltages are varying depending on the type of grid. In this type of grid, the given voltage level would be 120/240 V, but the real voltage given to the end users is actually 127/220 V. In order to assure this voltage, it is common that the grid companies step down the transformer a little bit, in order to raise the voltage about 2%, just as in Sweden. Therefore, the voltage is set to be around 129-130 V instead of 127 V.

The frequency is 60 Hz, and since there were no standards or guidelines about the accepted voltage deviation, the Swedish limits were used in order to set some guidelines for the grid. In the standards, there is no indication of maximum allowed short circuit current in the cables, but there are limits used for the fuses and protection. Therefore, the Venezuelan cables have been matched with the Swedish ones, and the Swedish limits have been used.

The Venezuelan transformer are set to be T1: 315 kVA, T2: 500 kVA in the Mini Grid and T1: 800 kVA and T2: 500 kVA in the Large Grid.

Table 5.6: The transformers in the Venezuelan grids

Grid	**T1 [kVA]**	**T2 [kVA]**
Large Grid	800	500
Mini Grid	315	500

Chapter 6

Simulations

In this chapter, all simulations made in the program PowerFactory will be presented. They have been used when dimensioning the grid. The simulations will show the voltage deviation at each bus bar in the grid, electrical loading on each cable, the total losses in the grid and finally, the short circuit currents calculated in accordance with an IEC method. In the end of the chapter there will be a summary of all simulations and a discussion about the results.

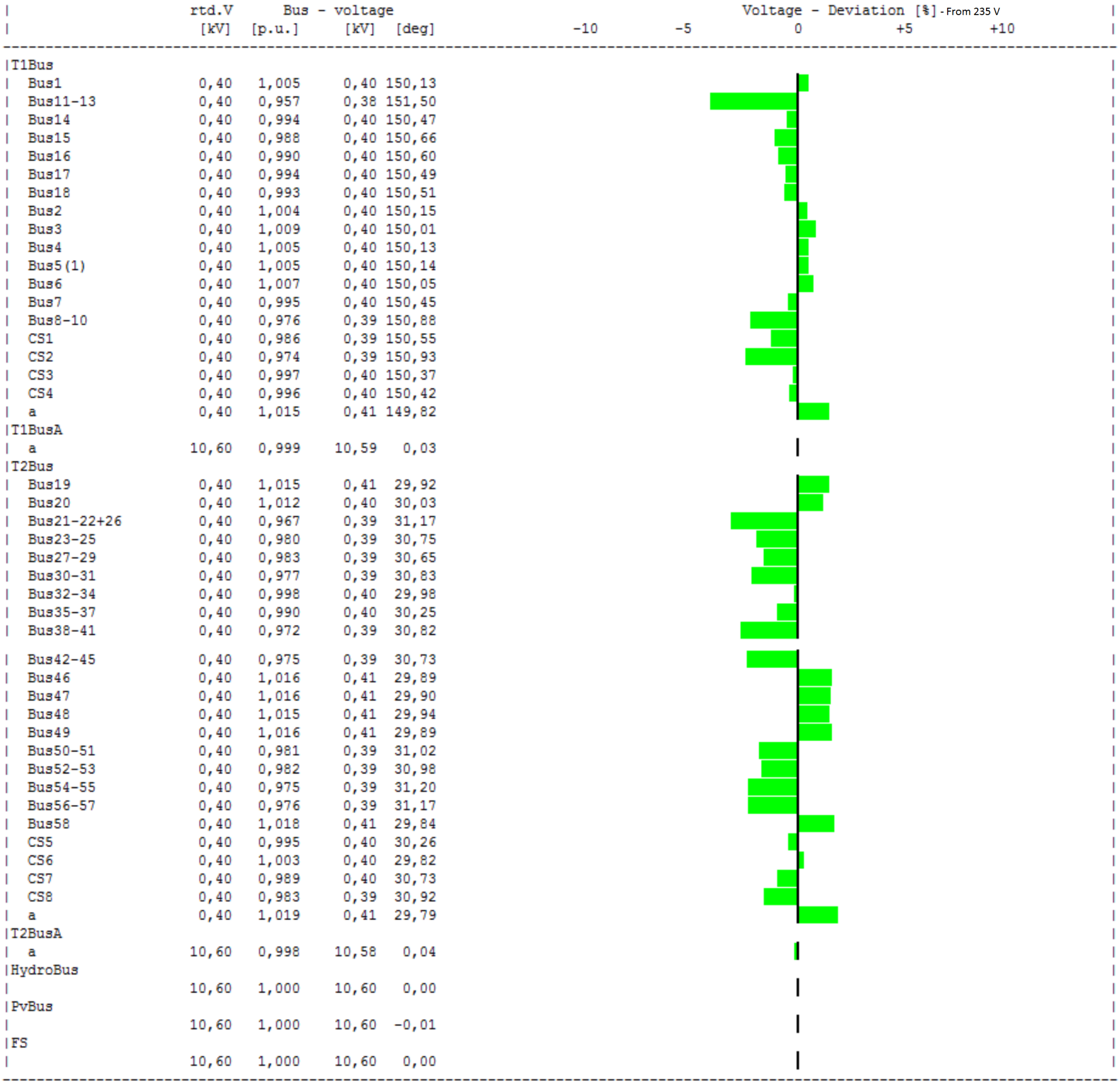
6.1 Voltage deviation

In line with the Swedish standards, presented in Chapter 4, the voltage deviation limit is not allowed to exceed +10/-15% to the end user in a island grid. As mentioned in Chapter 5.2, the limits used in this thesis are in accordance with the limits used by several Swedish distribution network companies, +6/-10%. Since no standards or guidelines about voltage deviation have been found regarding the Venezuelan grid, the same limits have been used in the Venezuelan model.

The voltage deviations for each bus bar in each grid (Scenario 1-4) are presented below, categorised as all bus bars after transformer 1, all bus bars after transformer 2 and also the bus bars for the hydro station, solar station and the distribution station (FS). All bus bars in the low voltage part of the grid uses 230 V (Sweden) and 127 V (Venezuela) as nominal voltage, and the bus bars in the high voltage part of the grid uses 10,6 kV (Sweden) and 10 kV (Venezuela) as reference voltage. As seen in Figure 6.1 to 6.4, the cables have been dimensioned so as the voltage never decreases below the given limit, 10%. This in turn will allow for a quality assurance for the electrical supply.

When designing the grid, the voltage deviation has been a large factor to consider in order to ensure the right voltage to the customer. The cables were, as mentioned in Chapter 5, dimensioned after the calculated current, but when running the simulations, some cables needed to be changed into large ones if the voltage at the end load has dropped below the given limit. All cables, for all scenarios, are presented in Appendix C.

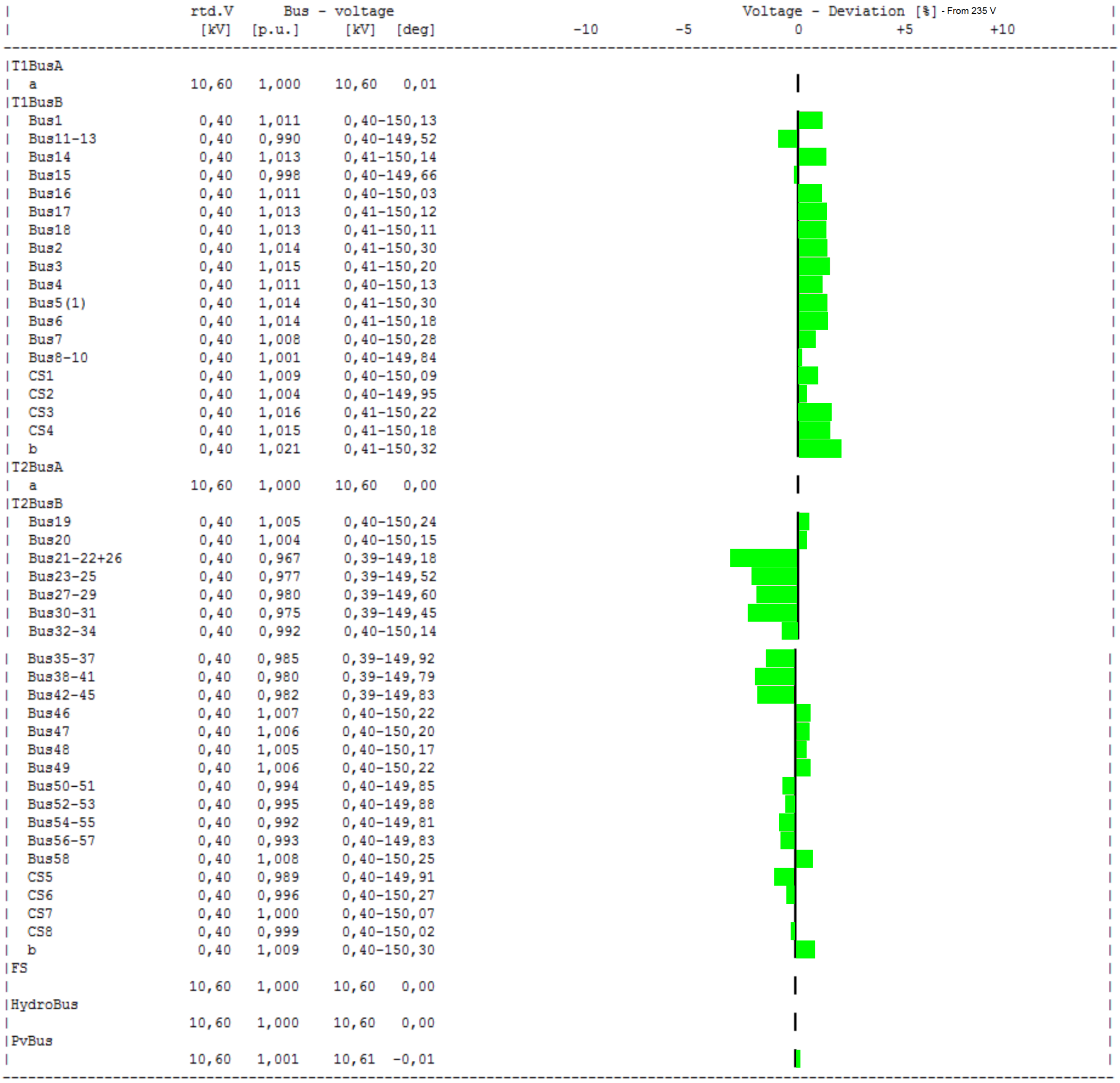
Voltage deviation - Swedish Mini Grid



	rtd.V [kV]	Bus - voltage [p.u.]	[kV]	[deg]
T1Bus				
Bus1	0,40	1,005	0,40	150,13
Bus11-13	0,40	0,957	0,38	151,50
Bus14	0,40	0,994	0,40	150,47
Bus15	0,40	0,988	0,40	150,66
Bus16	0,40	0,990	0,40	150,60
Bus17	0,40	0,994	0,40	150,49
Bus18	0,40	0,993	0,40	150,51
Bus2	0,40	1,004	0,40	150,15
Bus3	0,40	1,009	0,40	150,01
Bus4	0,40	1,005	0,40	150,13
Bus5(1)	0,40	1,005	0,40	150,14
Bus6	0,40	1,007	0,40	150,05
Bus7	0,40	0,995	0,40	150,45
Bus8-10	0,40	0,976	0,39	150,88
CS1	0,40	0,986	0,39	150,55
CS2	0,40	0,974	0,39	150,93
CS3	0,40	0,997	0,40	150,37
CS4	0,40	0,996	0,40	150,42
a	0,40	1,015	0,41	149,82
T1BusA				
a	10,60	0,999	10,59	0,03
T2Bus				
Bus19	0,40	1,015	0,41	29,92
Bus20	0,40	1,012	0,40	30,03
Bus21-22+26	0,40	0,967	0,39	31,17
Bus23-25	0,40	0,980	0,39	30,75
Bus27-29	0,40	0,983	0,39	30,65
Bus30-31	0,40	0,977	0,39	30,83
Bus32-34	0,40	0,998	0,40	29,98
Bus35-37	0,40	0,990	0,40	30,25
Bus38-41	0,40	0,972	0,39	30,82
Bus42-45	0,40	0,975	0,39	30,73
Bus46	0,40	1,016	0,41	29,89
Bus47	0,40	1,016	0,41	29,90
Bus48	0,40	1,015	0,41	29,94
Bus49	0,40	1,016	0,41	29,89
Bus50-51	0,40	0,981	0,39	31,02
Bus52-53	0,40	0,982	0,39	30,98
Bus54-55	0,40	0,975	0,39	31,20
Bus56-57	0,40	0,976	0,39	31,17
Bus58	0,40	1,018	0,41	29,84
CS5	0,40	0,995	0,40	30,26
CS6	0,40	1,003	0,40	29,82
CS7	0,40	0,989	0,40	30,73
CS8	0,40	0,983	0,39	30,92
a	0,40	1,019	0,41	29,79
T2BusA				
a	10,60	0,998	10,58	0,04
HydroBus	10,60	1,000	10,60	0,00
PvBus	10,60	1,000	10,60	-0,01
FS	10,60	1,000	10,60	0,00

Figure 6.1: Voltage deviation on each bus, Swedish Mini grid

Voltage deviation - Swedish Large Grid



	rtd.V [kV]	Bus - voltage [p.u.]	[kV]	[deg]
T1BusA				
a	10,60	1,000	10,60	0,01
T1BusB				
Bus1	0,40	1,011	0,40	-150,13
Bus11-13	0,40	0,990	0,40	-149,52
Bus14	0,40	1,013	0,41	-150,14
Bus15	0,40	0,998	0,40	-149,66
Bus16	0,40	1,011	0,40	-150,03
Bus17	0,40	1,013	0,41	-150,12
Bus18	0,40	1,013	0,41	-150,11
Bus2	0,40	1,014	0,41	-150,30
Bus3	0,40	1,015	0,41	-150,20
Bus4	0,40	1,011	0,40	-150,13
Bus5(1)	0,40	1,014	0,41	-150,30
Bus6	0,40	1,014	0,41	-150,18
Bus7	0,40	1,008	0,40	-150,28
Bus8-10	0,40	1,001	0,40	-149,84
CS1	0,40	1,009	0,40	-150,09
CS2	0,40	1,004	0,40	-149,95
CS3	0,40	1,016	0,41	-150,22
CS4	0,40	1,015	0,41	-150,18
b	0,40	1,021	0,41	-150,32
T2BusA				
a	10,60	1,000	10,60	0,00
T2BusB				
Bus19	0,40	1,005	0,40	-150,24
Bus20	0,40	1,004	0,40	-150,15
Bus21-22+26	0,40	0,967	0,39	-149,18
Bus23-25	0,40	0,977	0,39	-149,52
Bus27-29	0,40	0,980	0,39	-149,60
Bus30-31	0,40	0,975	0,39	-149,45
Bus32-34	0,40	0,992	0,40	-150,14
Bus35-37	0,40	0,985	0,39	-149,92
Bus38-41	0,40	0,980	0,39	-149,79
Bus42-45	0,40	0,982	0,39	-149,83
Bus46	0,40	1,007	0,40	-150,22
Bus47	0,40	1,006	0,40	-150,20
Bus48	0,40	1,005	0,40	-150,17
Bus49	0,40	1,006	0,40	-150,22
Bus50-51	0,40	0,994	0,40	-149,85
Bus52-53	0,40	0,995	0,40	-149,88
Bus54-55	0,40	0,992	0,40	-149,81
Bus56-57	0,40	0,993	0,40	-149,83
Bus58	0,40	1,008	0,40	-150,25
CS5	0,40	0,989	0,40	-149,91
CS6	0,40	0,996	0,40	-150,27
CS7	0,40	1,000	0,40	-150,07
CS8	0,40	0,999	0,40	-150,02
b	0,40	1,009	0,40	-150,30
FS				
	10,60	1,000	10,60	0,00
HydroBus				
	10,60	1,000	10,60	0,00
PvBus				
	10,60	1,001	10,61	-0,01

Figure 6.2: Voltage deviation on each bus, Swedish Large grid

Voltage deviation - Venezuelan Mini Grid

	rtd.V [kV]	Bus - voltage [p.u.]	[kV]	[deg]
BusHydro				
a	10,00	1,000	10,00	0,00
BusPV				
a	10,00	1,000	10,00	-0,01
FS				
a	10,00	1,000	10,00	0,00
T1				
Bus1	0,22	0,946	0,21	-27,77
Bus11-13	0,22	0,932	0,20	-28,49
Bus14	0,22	0,955	0,21	-28,20
Bus15	0,22	0,951	0,21	-28,14
Bus16	0,22	0,932	0,21	-27,48
Bus17	0,22	0,932	0,21	-27,42
Bus18	0,22	0,952	0,21	-28,14
Bus2	0,22	0,955	0,21	-28,08
Bus3	0,22	0,981	0,22	-28,92
Bus4	0,22	0,993	0,22	-29,40
Bus5	0,22	0,994	0,22	-29,44
Bus6	0,22	0,974	0,21	-28,68
Bus7	0,22	0,969	0,21	-28,67
Bus8-10	0,22	0,938	0,21	-28,40
CS1	0,22	0,964	0,21	-29,23
CS2	0,22	0,950	0,21	-28,97
CS3	0,22	0,974	0,21	-28,87
CS4	0,22	0,969	0,21	-28,75
b	0,22	1,020	0,22	-30,20
T1BusA				
a	10,00	0,999	9,99	0,02
T2				
Bus19	0,22	1,003	0,22	150,10
Bus20	0,22	0,995	0,22	150,36
Bus21-22+26	0,22	0,974	0,21	149,62
Bus23-25	0,22	0,970	0,21	149,70
Bus27-29	0,22	0,960	0,21	149,97
Bus30-31	0,22	0,968	0,21	149,76
Bus32-34	0,22	0,959	0,21	149,44
Bus35-37	0,22	0,936	0,21	150,14
Bus38-41	0,22	0,939	0,21	149,88
Bus42-45	0,22	0,937	0,21	150,11
Bus46	0,22	0,994	0,22	150,43
Bus47	0,22	0,991	0,22	150,54
Bus48	0,22	0,983	0,22	150,79
Bus49	0,22	0,994	0,22	150,44
Bus50-51	0,22	0,960	0,21	151,23
Bus52-53	0,22	0,963	0,21	151,14
Bus54-55	0,22	0,955	0,21	151,34
Bus56-57	0,22	0,956	0,21	151,30
Bus58	0,22	1,003	0,22	150,15
CS5	0,22	0,986	0,22	149,29
CS6	0,22	0,972	0,21	149,03
CS7	0,22	0,982	0,22	150,54
CS8.	0,22	0,976	0,21	150,70
b	0,22	1,014	0,22	149,77
T2BusA				
a	10,00	0,998	9,98	0,04

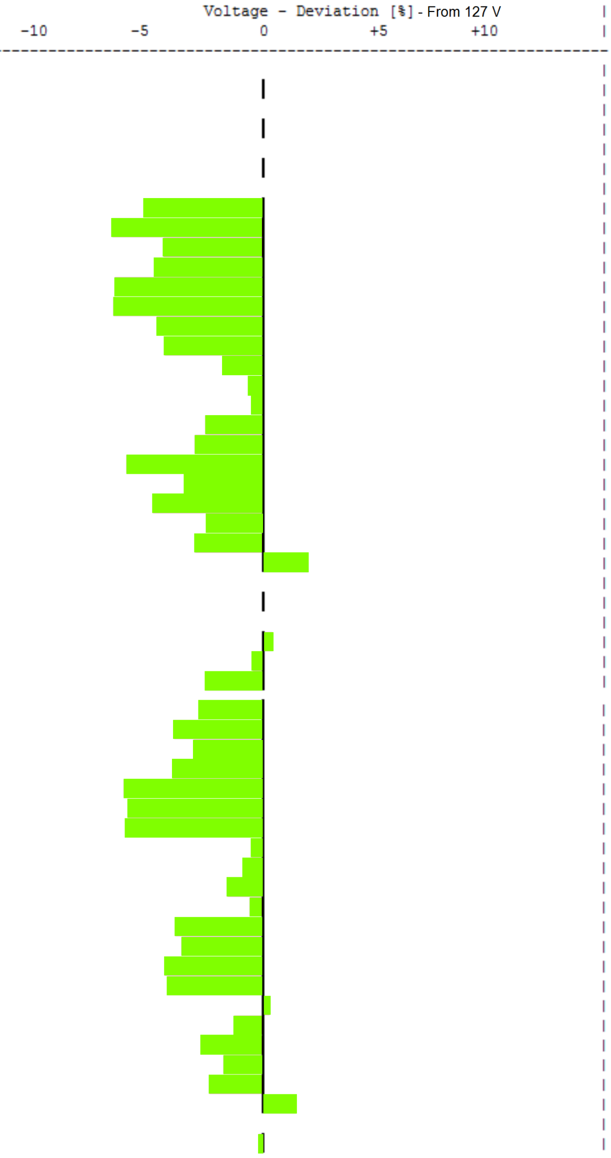


Figure 6.3: Voltage deviation on each bus, Venezuelan Mini grid

Voltage deviation - Venezuelan Large Grid

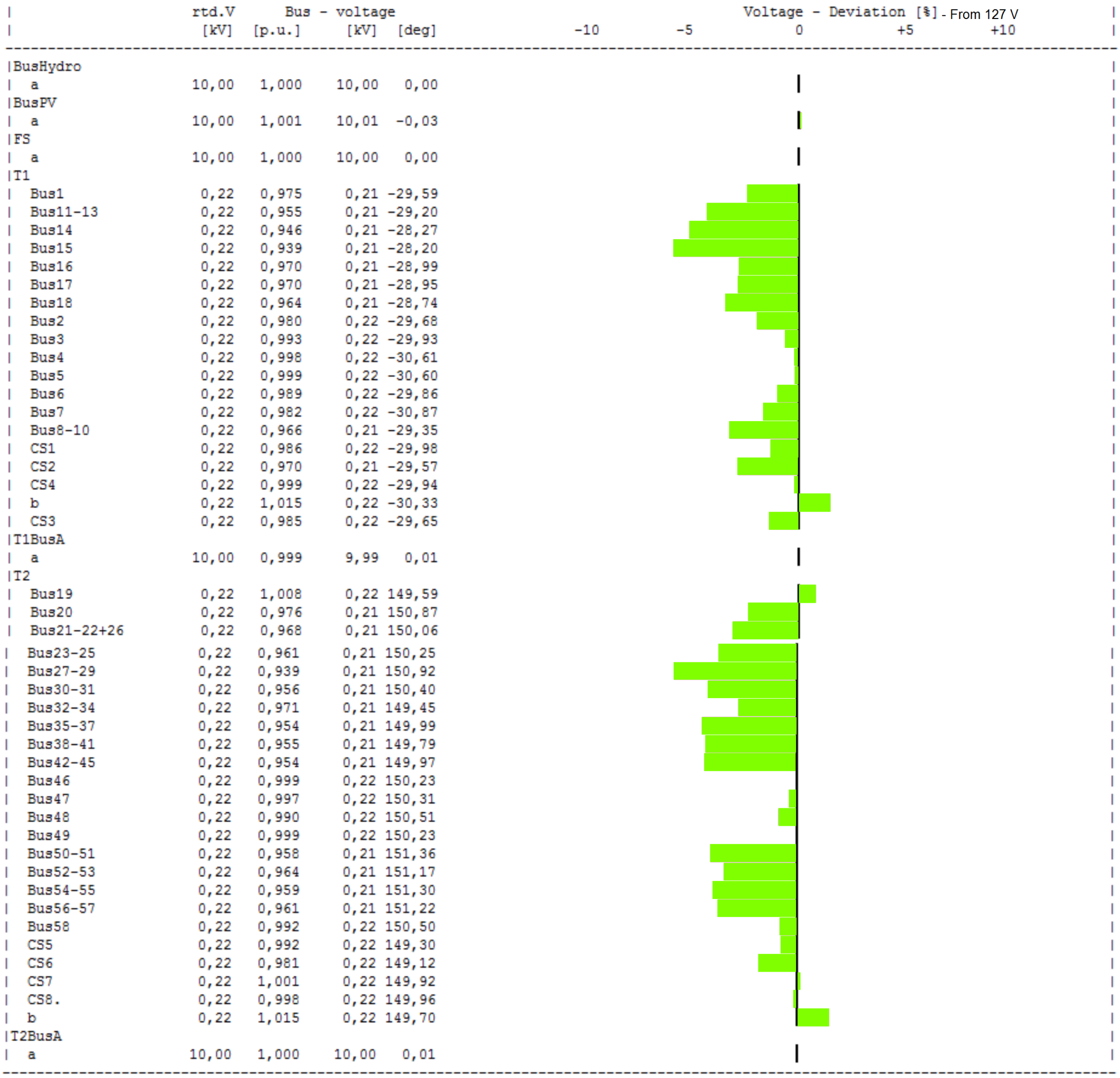


Figure 6.4: Voltage deviation on each bus, Venezuelan Large grid

6.2 Electrical loading

The electrical loading on each cable will affect the losses on the cable, but also the lifetime of the cable. A normal limit to aim for, according to ÅF and the guidelines of many grid companies in Sweden, is an electrical loading of around 60-80% on each cable, depending on the size and the end load. For a transformer, the accepted electrical loading would be around 90%. The grid companies in Sweden aim to change the cables as little as possible. Current lifetime expectancy is around 30-40 years, depending on the system, but with a low electrical loading, the cables can maintain integrity and function properly much longer.

Presented below are all load simulations for each scenario, and the electrical loading on each cable and equipment. The electrical loading is presented as a percentage, which indicates how much of the cable's or equipment's capacity that is used. For example, in the first figure below, Figure 6.5, the cable from the distribution station (FS) to transformer number 1 (T1), the electrical loading is only 5.1%

Electrical loading - Swedish Mini Grid

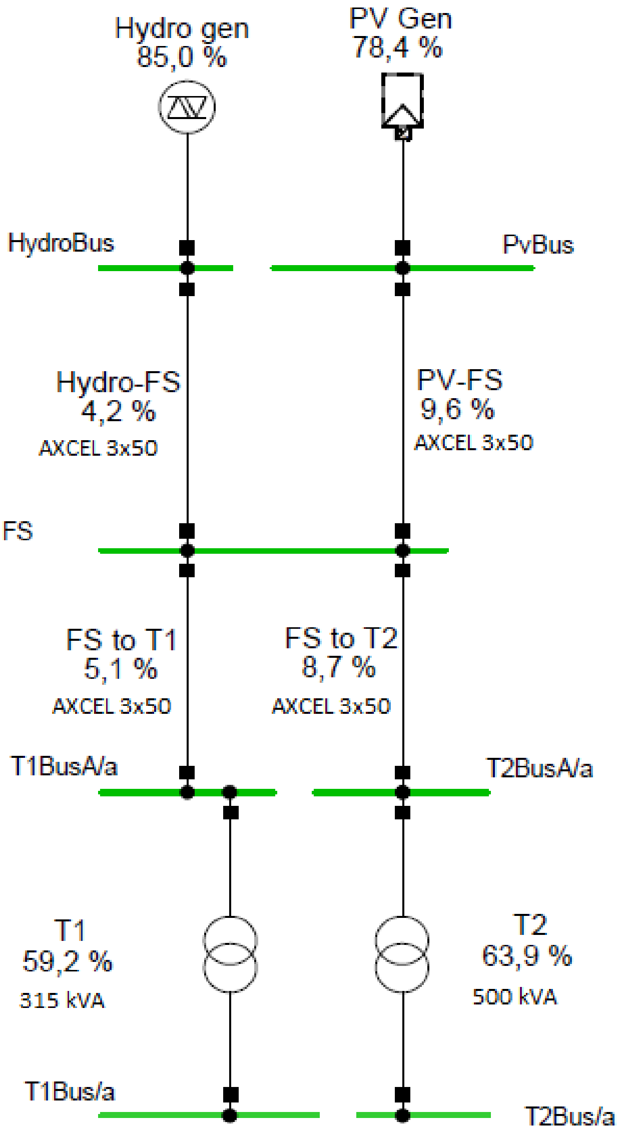
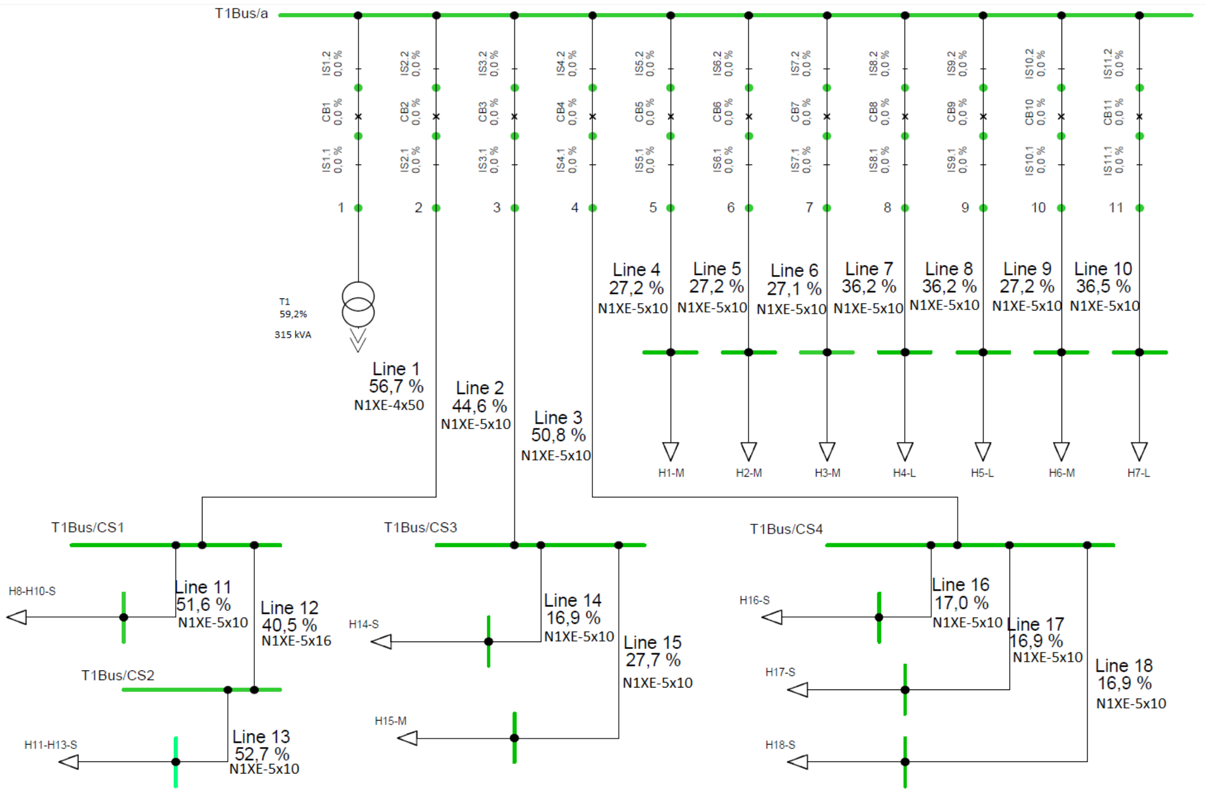
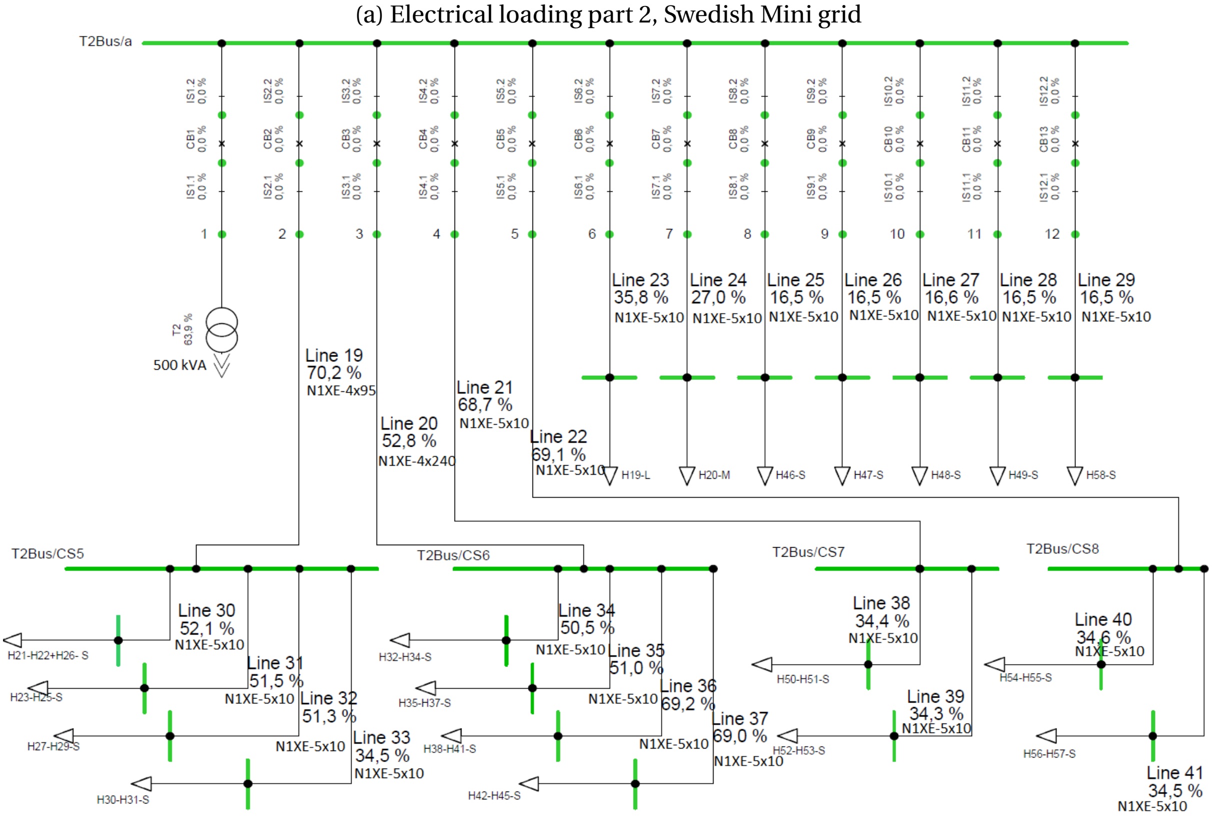


Figure 6.5: Electrical loading on each cable and equipment in percentage of used capacity. Part 1, Swedish Mini grid



(a) Electrical loading part 2, Swedish Mini grid



(b) Electrical loading part 3, Swedish Mini grid

Figure 6.6: Electrical loading on each cable and equipment in percentage of used capacity. Part 2 and 3, Swedish Mini grid

Electrical loading - Swedish Large Grid

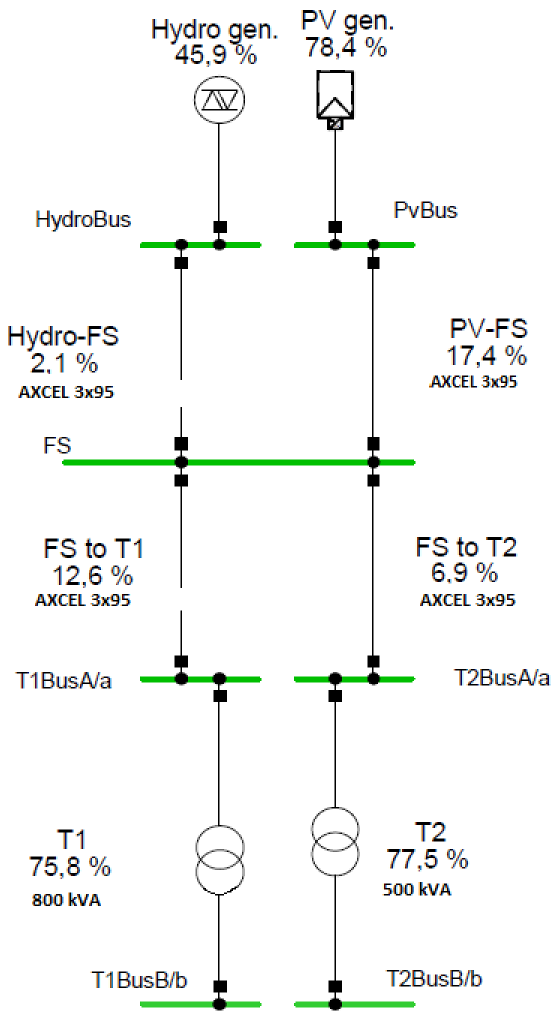
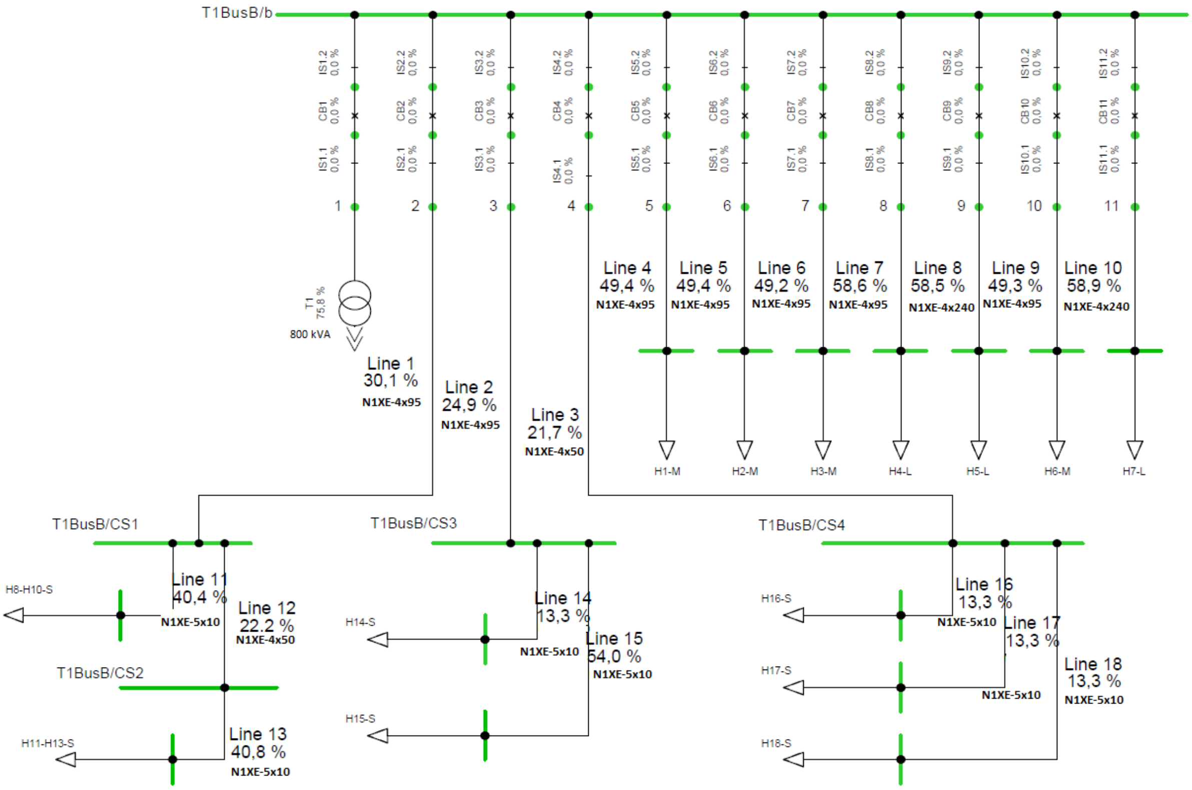
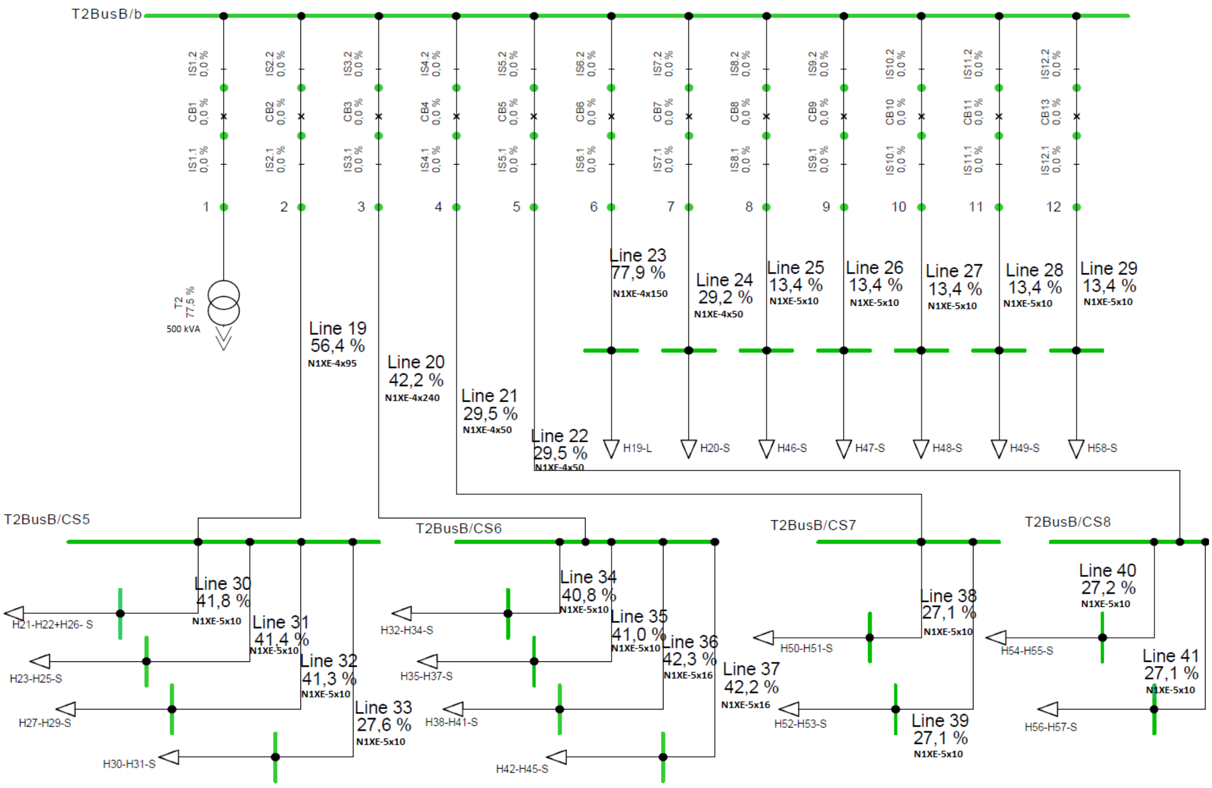


Figure 6.7: Electrical loading on each cable and equipment in percentage of used capacity. Part 1, Swedish Large grid



(a) Electrical loading, part 2, Swedish Large grid



(b) Electrical loading part 3, Swedish Large grid

Figure 6.8: Electrical loading on each cable and equipment in percentage of used capacity. Part 2 and 3, Swedish Large grid

Electrical loading - Venezuelan Mini Grid

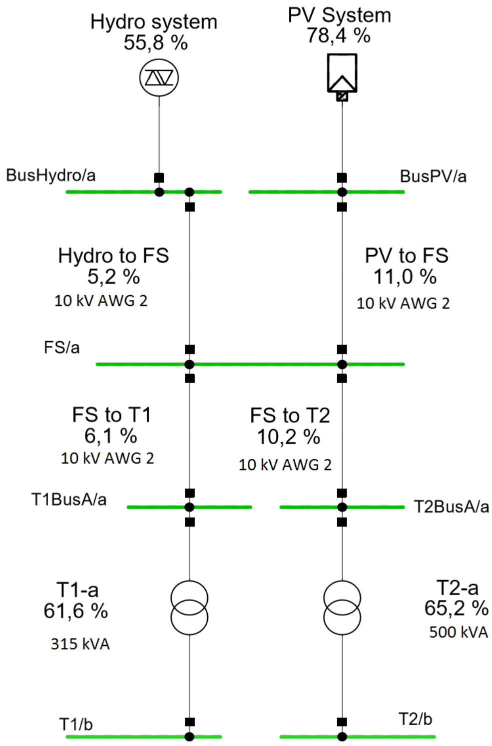


Figure 6.9: Electrical loading on each cable and equipment in percentage of used capacity. Part 1, Venezuelan Mini grid

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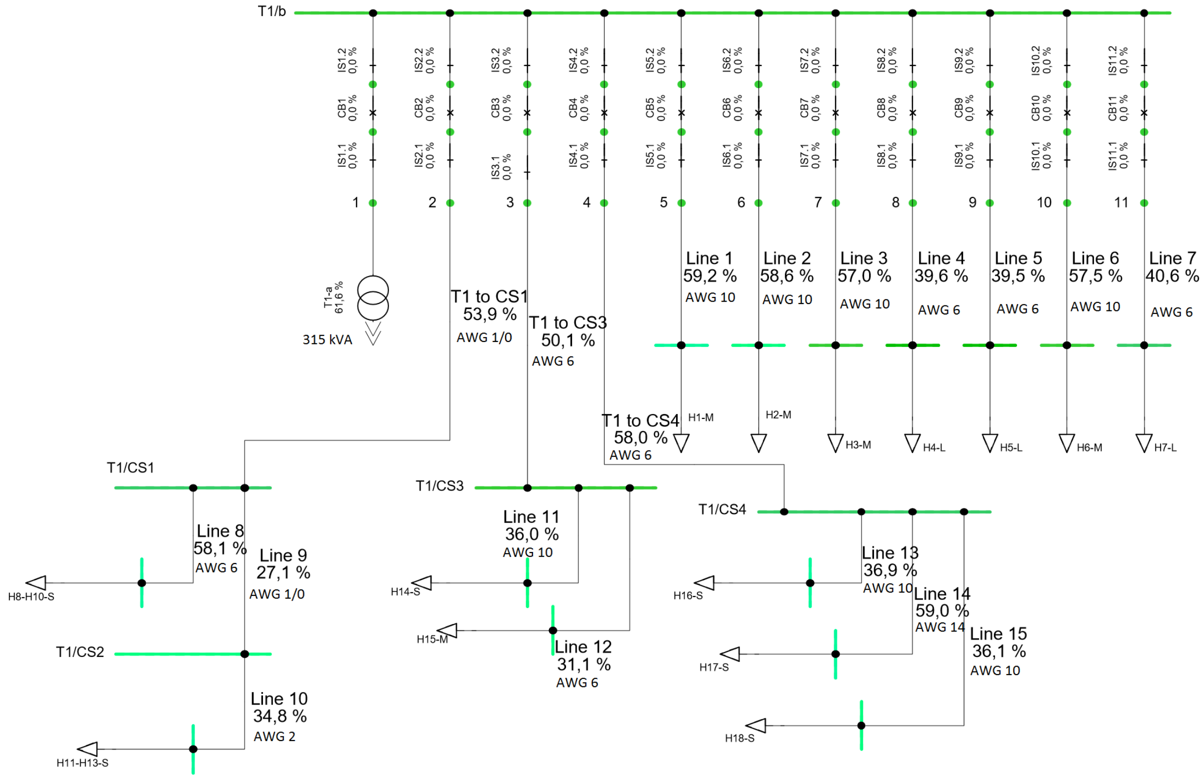
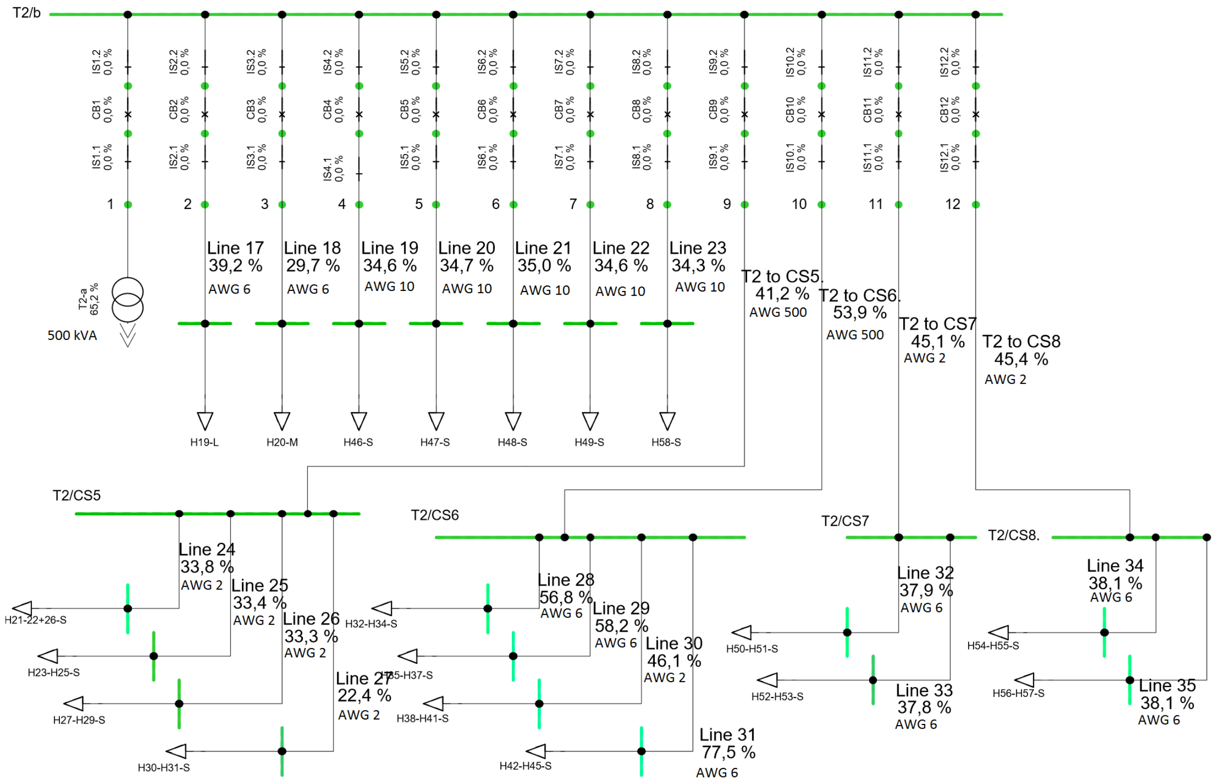


(a) Electrical loading part 2, Venezuelan Mini grid



(b) Electrical loading part 3, Venezuelan Mini grid

Figure 6.10: Electrical loading on each cable and equipment in percentage of used capacity. Part 2 and 3, Venezuelan Mini grid

Electrical loading - Venezuelan Large Grid

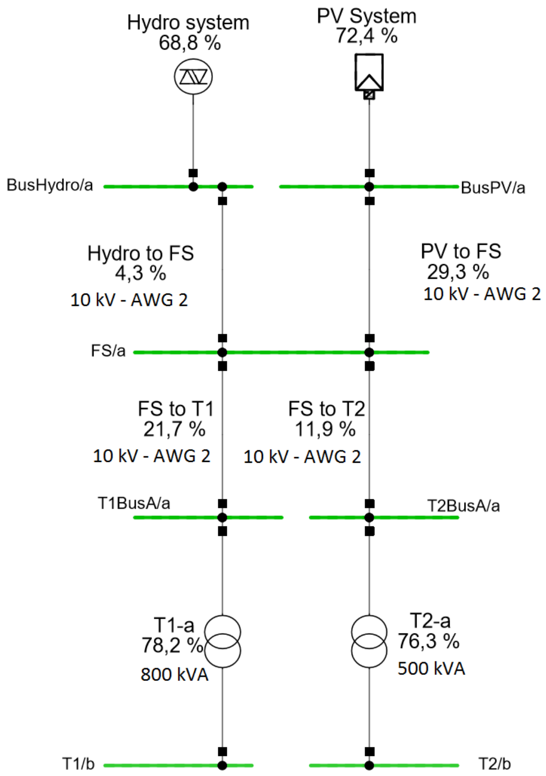
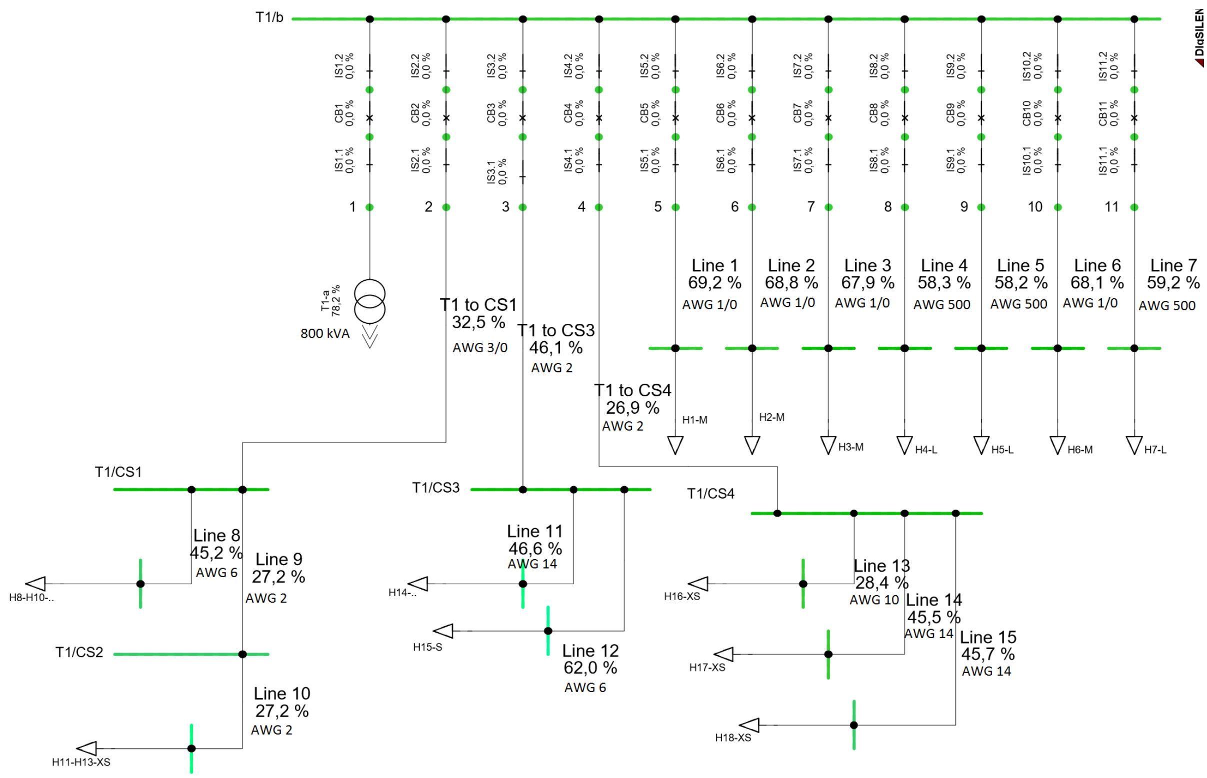
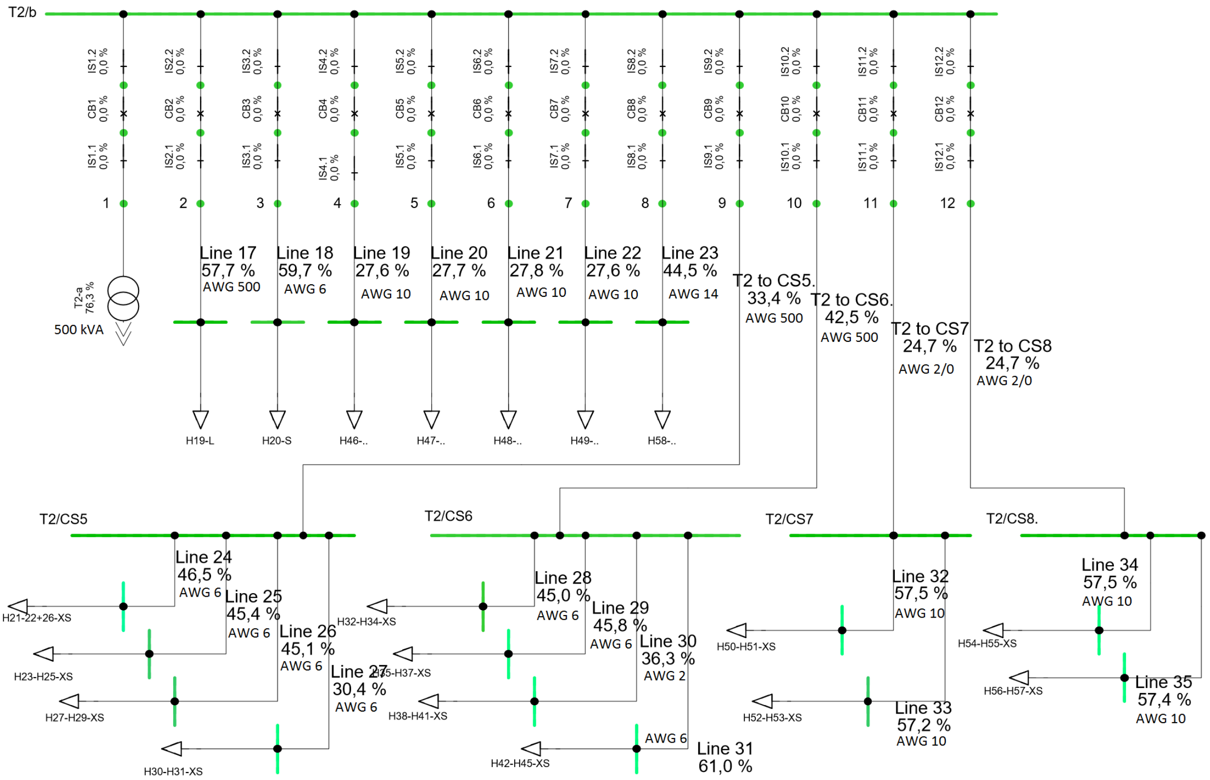


Figure 6.11: Electrical loading on each cable and equipment in percentage of used capacity. Part 1, Venezuelan Large grid



(a) Electrical loading part 2, Venezuelan Large grid



(b) Electrical loading part 3, Venezuelan Large grid

Figure 6.12: Electrical loading on each cable and equipment in percentage of used capacity. Part 2 and 3, Venezuelan Large grid

6.3 Losses

The losses of each grid has been calculated in PowerFactory, with the Complete System Report, based on the Load Flow Calculations. The output (System summary), as a figure, and the calculated percentage of the losses will be presented. The losses depend on the size of the cables and the electrical loading on them. A smaller electrical loading would give smaller losses, and therefore, a larger cable would give smaller losses. The losses in these simulations are calculated for the worst case scenario, i.e. maximum load, and therefore, the losses are also the maximum losses, or the worst case losses. In this thesis, only the active losses will be discussed and compared, because the active power is the power calculated for the client/end user.

Losses - Swedish Mini Grid

Total System Summary | Study Case: Swedish mini grid | Annex: / 4

	Generation [MW]/ [Mvar]	Motor Load [MW]/ [Mvar]	Load [MW]/ [Mvar]	Compen-sation [MW]/ [Mvar]	External Infeed [MW]/ [Mvar]	Inter Area Flow [MW]/ [Mvar]	Total Losses [MW]/ [Mvar]	Load Losses [MW]/ [Mvar]	Noload Losses [MW]/ [Mvar]
\magda\Project\Network Model\Network Data\Swedish mini grid									
	0,43	0,00	0,41	0,00	0,00	0,00	0,02	0,02	0,00
	0,26	0,00	0,26	0,00	0,00	0,00	0,01	0,00	0,00
Total:									
	0,43	0,00	0,41	0,00	0,00		0,02	0,02	0,00
	0,26	0,00	0,26	0,00	0,00		0,01	0,00	0,00

Figure 6.13: System summary, Swedish Mini grid

Here it shows that the generated load is 0,43 MW and the transmitted power is 0,41 MW. The total losses are 0,02 MW and this gives 4,87% of active losses in the system.

Losses - Swedish Large Grid

Total System Summary | Study Case: Swedish all large | Annex: / 4

	Generation [MW]/ [Mvar]	Motor Load [MW]/ [Mvar]	Load [MW]/ [Mvar]	Compen-sation [MW]/ [Mvar]	External Infeed [MW]/ [Mvar]	Inter Area Flow [MW]/ [Mvar]	Total Losses [MW]/ [Mvar]	Load Losses [MW]/ [Mvar]	Noload Losses [MW]/ [Mvar]
\magda\Project\Network Model\Network Data\Swedish all Large									
	0,90	0,00	0,88	0,00	0,00	0,00	0,02	0,01	0,00
	0,56	0,00	0,55	0,00	0,00	0,00	0,01	0,01	0,00
Total:									
	0,90	0,00	0,88	0,00	0,00		0,02	0,01	0,00
	0,56	0,00	0,55	0,00	0,00		0,01	0,01	0,00

Figure 6.14: System summary, Swedish Large grid

In this grid, the generated power is 0,9 MW, and the transmitted power is 0.88 MW. The losses are 0,02 MW and therefore the active losses in the system are 2,27%.

Losses - Venezuelan Mini Grid

Total System Summary						Study Case: Venezuelan mini grid		Annex:	/ 4
	Generation [MW]/ [Mvar]	Motor Load [MW]/ [Mvar]	Load [MW]/ [Mvar]	Compen- sation [MW]/ [Mvar]	External Infeed [MW]/ [Mvar]	Inter Area Flow [MW]/ [Mvar]	Total Losses [MW]/ [Mvar]	Load Losses [MW]/ [Mvar]	Noload Losses [MW]/ [Mvar]
\magda\Project\Network Model\Network Data\Venezuelan mini grid									
	0,45	0,00	0,41	0,00	0,00	0,00	0,03	0,03	0,00
	0,27	0,00	0,26	0,00	0,00	0,00	0,01	0,01	0,00
Total:									
	0,45	0,00	0,41	0,00	0,00		0,03	0,03	0,00
	0,27	0,00	0,26	0,00	0,00		0,01	0,01	0,00

Figure 6.15: System summary, Venezuelan Mini grid

In this Venezuelan mini grid, the total generated power is 0,45 MW, but the transmitted power is still the same as in the Swedish Mini grid, 0,41 MW. The losses are then 0,03 MW, and gives 7,32% active losses.

Losses - Venezuelan Large Grid

	Generation [MW]/ [Mvar]	Motor Load [MW]/ [Mvar]	Load [MW]/ [Mvar]	Compen- sation [MW]/ [Mvar]	External Infeed [MW]/ [Mvar]	Inter Area Flow [MW]/ [Mvar]	Total Losses [MW]/ [Mvar]	Load Losses [MW]/ [Mvar]	Noload Losses [MW]/ [Mvar]
\magda\Project\Network Model\Network Data\Venezuelas Large Grid									
	0,92	0,00	0,88	0,00	0,00	0,00	0,04	0,03	0,00
	0,56	0,00	0,55	0,00	0,00	0,00	0,02	0,02	-0,00
Total:									
	0,92	0,00	0,88	0,00	0,00		0,04	0,03	0,00
	0,56	0,00	0,55	0,00	0,00		0,02	0,02	-0,00

Figure 6.16: System summary, Venezuelan Large grid

Here, the total grid losses are 4,55% of active losses. In this grid there are 0,04 MW load losses. The generated power is 0,92 MW and the transmitted power 0,88 MW.

Losses - comparison of all grids

Table 6.1: Total Grid losses

Grid	Total Losses	Transmitted power	Losses of transmitted power
Swedish Mini Grid	0,02 MW	0,41 MW	4,87%
Swedish Large Grid	0,02 MW	0,88 MW	2,27%
Venezuelan Mini Grid	0,03 MW	0,41 MW	7,32%
Venezuelan Large Grid	0,04 MW	0,88 MW	4,55%

As seen in the table above, the percentage of losses in the Venezuelan grids are higher than the losses in the Swedish grids. The notable difference is the difference between the Mini grids and the Large grids, i.e. load profile 1 and load profile 2. Load profile 1 causes almost twice the losses as load profile 2.

6.4 Short circuit currents

To calculate the short circuit currents in the system and to ensure that the cables can handle them, the method described in IEC 61363 was used in the program PowerFactory. The method calculates three-phase short circuit currents in three-phase AC radial electrical installations, with zero fault impedance. This is not the most common calculation method to use when calculation short circuit currents in PowerFactory, but it is the only method that allows a grid without a connection to an external grid, and only supply from generators within the grid.

The chosen break time in the calculation is 0,1 s, as given in the standards, see Chapter 4 or Appendix A. The faults are located on each bus bar and junction node, one at a time.

The short circuit current calculation also contributed to the choice of cable, when dimension the grid. After having chosen the cable with help of the current calculations and then changing some cables due to voltage deviation, the short circuit currents were calculated. If the current exceeded the given limit of the cable, see Chapter 5.2, then the cable needed to be changed into a larger one. This will be presented in the tables below, in the peak current column, "Ip<Limit?", and "New Cable", but can also be seen in Appendix C.

As mentioned in the previous chapter, maximum short circuit current for the Venezuelan cables were not found, and therefore the corresponding limits for the Swedish cables were used, as well as the break time.

Short circuit currents - Swedish Mini Grid

Table 6.2: Short circuit currents, break time=0,1 s, Swedish Mini Grid

From	To	Ip [A]	Cable	Limit [A]	Ip<Limit?	New Cable
Hydro	FS	16	AXCEL3x50	4720	YES	-
PV	FS	36	AXCEL3X50	4720	YES	-
FS	T1	52	AXCEL3X50	4720	YES	-
FS	T2	52	AXCEL3X50	4720	YES	-
T1	H1	871	N1XE-U5G10	1 430	YES	-
T1	H2	873	N1XE-U5G10	1 430	YES	-
T1	H3	1002	N1XE-U5G10	2 290	YES	-
T1	H4	935	N1XE-U5G10	1 430	YES	-
T1	H5	949	N1XE-U5G10	1 430	YES	-
T1	H6	958	N1XE-U5G10	1 430	YES	-
T1	H7	740	N1XE-U5G10	1 430	YES	-
T1	CS1	957	N1XE-A4X50	4 720	YES	-
T1	CS3	847	N1XV-U5G10	1 430	YES	-
T1	CS4	862	N1XV-U5G10	1 430	YES	-
CS1	H8-10	792	N1XE-U5G10	1 430	YES	-
CS1	CS2	764	N1XE-U5G16	2 290	YES	-
CS2	H11-H13	598	N1XE-U5G10	1 430	YES	-
CS3	H14	724	N1XE-U5G10	1 430	YES	-
CS3	H15	648	N1XE-U5G10	1 430	YES	-
CS4	H16	652	N1XE-U5G10	1 430	YES	-
CS4	H17	763	N1XE-U5G10	1 430	YES	-
CS4	H18	745	N1XE-U5G10	1 430	YES	-
T2	H19	1 153	N1XE-U5G10	1 430	YES	-
T2	H20	951	N1XE-U5G10	1 430	YES	-
T2	H46	1 050	N1XE-U5G10	1 430	YES	-

From	To	Ip [A]	Cable	Limit [A]	Ip<Limit?	New Cable
T2	H47	1 015	N1XE-U5G10	1 430	YES	-
T2	H48	937	N1XE-U5G10	1 430	YES	-
T2	H49	1 048	N1XE-U5G10	1 430	YES	-
T2	H58	1 163	N1XE-U5G10	1 430	YES	-
T2	CS5	1 139	N1XE-A4X95	22 700	YES	-
T2	CS6	1 237	N1XE-A4X240	22 700	YES	-
T2	CS7	814	N1XE-U5G16	2 290	YES	-
T2	CS8	757	N1XE-U5G16	2 290	YES	-
CS5	H21,22,26	676	N1XE-U5G10	1 430	YES	-
CS5	H23-H25	827	N1XE-U5G10	1 430	YES	-
CS5	H27-H29	874	N1XE-U5G10	1 430	YES	-
CS5	H30-H31	690	N1XE-U5G10	1 430	YES	-
CS6	H32-H34	1 088	N1XE-U5G10	1 430	YES	-
CS6	H35-H37	904	N1XE-U5G10	1 430	YES	-
CS6	H38-H41	762	N1XE-U5G16	2 290	YES	-
CS6	H42-H45	787	N1XE-U5G16	2 290	YES	-
CS7	H50-H51	663	N1XE-U5G10	1 430	YES	-
CS7	H52-H53	680	N1XE-U5G10	1 430	YES	-
CS8	H54-H55	628	N1XE-U5G10	1 430	YES	-
CS8	H56-H57	638	N1XE-U5G10	1 430	YES	-

Short circuit currents - Swedish Large Grid

Table 6.3: Short circuit currents, break time=0,1 s, Swedish Large Grid

From	To	Ip [A]	Cable	Limit [A]	Ip<Limit?	New cable
Hydro	FS	12	AXCEL3x95	8 980	YES	-
PV	FS	97	AXCEL3X95	8 980	YES	-
FS	T1	109	AXCEL3X95	8 980	YES	-
FS	T2	109	AXCEL3X95	8 980	YES	-
T1	H1	2 324	N1XE-A4X95	8 980	YES	-
T1	H2	2 327	N1XE-A4X95	8 980	YES	-
T1	H3	2 493	N1XE-A4X95	8 980	YES	-
T1	H4	2 632	N1XE-A4X240	22 700	YES	-
T1	H5	2 641	N1XE-A4X240	22 700	YES	-
T1	H6	2 439	N1XE-A4X95	8 980	YES	-
T1	H7	2 468	N1XE-A4X240	22 700	YES	-
T1	CS1	1 948	N1XE-A4X95	8 980	YES	-
T1	CS3	2 290	N1XV-A4X95	8 980	YES	-
T1	CS4	1 976	N1XV-A4X50	4 720	YES	-
CS1	H8-10	1 369	N1XE-U5G10	1 430	YES	-
CS1	CS2	1 504	N1XE-A4X50	4 720	YES	-
CS2	H11-H13	968	N1XE-U5G10	1 430	YES	-
CS3	H14	1 564	N1XE-U5G10	1 430	NO	N1XE-U5G16
CS3	H15	1 248	N1XE-U5G10	1 430	YES	-
CS4	H16	1 135	N1XE-U5G10	1 430	YES	-
CS4	H17	1 521	N1XE-U5G10	1 430	NO	N1XE-U5G16
CS4	H18	1 454	N1XE-U5G10	1 430	NO	N1XE-U5G16
T2	H19	2 778	N1XE-A4X150	14 200	YES	-
T2	H20	2 259	N1XE-A4X50	4 720	YES	-
T2	H46	1 757	N1XE-U5G10	1 430	NO	N1XE-U5G16
T2	H47	1 658	N1XE-U5G10	1 430	NO	N1XE-U5G16

From	To	Ip [A]	Cable	Limit [A]	Ip<Limit?	New cable
T2	H48	1 456	N1XE-U5G10	1 430	NO	N1XE-U5G16
T2	H49	1 749	N1XE-U5G10	1 430	NO	N1XE-U5G16
T2	H58	2 105	N1XE-U5G10	1 430	NO	N1XE-U5G16
T2	CS5	2 024	N1XE-A4X95	8 980	YES	-
T2	CS6	2 367	N1XE-A4X240	22 700	YES	-
T2	CS7	1 885	N1XE-A4X50	4 720	YES	-
T2	CS8	1 767	N1XE-A4X50	4 720	YES	-
CS5	H21,22,26	888	N1XE-U5G10	1 430	YES	-
CS5	H23-H25	1 297	N1XE-U5G10	1 430	YES	-
CS5	H27-H29	1 304	N1XE-U5G10	1 430	YES	-
CS5	H30-H31	914	N1XE-U5G10	1 430	YES	-
CS6	H32-H34	1 864	N1XE-U5G10	1 430	NO	N1XE-U5G16
CS6	H35-H37	1 375	N1XE-U5G10	1 430	YES	-
CS6	H38-H41	1 327	N1XE-U5G16	2 290	YES	-
CS6	H42-H45	1 379	N1XE-U5G16	2 290	YES	-
CS7	H50-H51	1 217	N1XE-U5G10	1 430	YES	-
CS7	H52-H53	1 279	N1XE-U5G10	1 430	YES	-
CS8	H54-H55	1 181	N1XE-U5G10	1 430	YES	-
CS8	H56-H57	1 219	N1XE-U5G10	1 430	YES	-

Short circuit currents - Venezuelan Mini Grid

Table 6.4: Short circuit currents, break time=0,1 s, Venezuelan Mini Grid

From	To	Ip [A]	Cable (AWG)	Limit [A]	Ip<Limit?	New Cable
Hydro	FS	19	10kV - 2	4720	YES	-
PV	FS	39	10kV - 2	4720	YES	-
FS	T1	59	10kV - 2	4720	YES	-
FS	T2	59	10kV - 2	4720	YES	-
T1	H1	490	10	1 430	YES	-
T1	H2	547	10	1 430	YES	-
T1	H3	793	10	1 430	YES	-
T1	H4	1 195	6	2 290	YES	-
T1	H5	1 225	6	2 290	YES	-
T1	H6	702	10	1 430	YES	-
T1	H7	810	6	2 290	YES	-
T1	CS1	1 424	1/0	14 200	YES	-
T1	CS3	1 009	6	2 290	YES	-
T1	CS4	1 038	6	2 290	YES	-
CS1	H8-10	998	6	2 290	YES	-
CS1	CS2	1 162	1/0	14 200	YES	-
CS2	H11-H13	935	2	8 980	YES	-
CS3	H14	585	10	1 430	YES	-
CS3	H15	660	6	2 290	YES	-
CS4	H16	431	10	1 430	YES	-
CS4	H17	426	14	1 430	YES	-
CS4	H18	662	10	1 430	YES	-
T2	H19	1 768	6	2 290	YES	-
T2	H20	1 225	6	2 290	YES	-
T2	H46	896	10	1 430	YES	-

From	To	Ip [A]	Cable (AWG)	Limit [A]	Ip<Limit?	New Cable
T2	H47	811	10	1 430	YES	-
T2	H48	656	10	1 430	YES	-
T2	H49	889	10	1 430	YES	-
T2	H58	1 242	10	1 430	YES	-
T2	CS5	2 144	500	22 700	YES	-
T2	CS6	2 079	500	22 700	YES	-
T2	CS7	1 510	2	8 980	YES	-
T2	CS8	1 396	2	8 980	YES	-
CS5	H21,22,26	1 276	2	8 980	YES	-
CS5	H23-H25	1 521	2	8 980	YES	-
CS5	H27-H29	1 611	2	8 980	YES	-
CS5	H30-H31	1 258	2	8 980	YES	-
CS6	H32-H34	1 564	6	2 290	YES	-
CS6	H35-H37	1 124	6	2 290	YES	-
CS6	H38-H41	1 298	2	8 980	YES	-
CS6	H42-H45	1 279	6	2 290	YES	-
CS7	H50-H51	950	6	2 290	YES	-
CS7	H52-H53	999	6	2 290	YES	-
CS8	H54-H55	929	6	2 290	YES	-
CS8	H56-H57	947	6	2 290	YES	-

Short circuit currents - Venezuelan Large Grid

Table 6.5: Short circuit currents, break time=0,1 s, Venezuelan Large Grid

From	To	Ip [A]	Cable (AWG)	Limit [A]	Ip<Limit?	New Cable
Hydro	FS	15	10kV - 2	4720	YES	-
PV	FS	103	10kV - 2	4720	YES	-
FS	T1	122	10kV - 2	4720	YES	-
FS	T2	122	10kV - 2	4720	YES	-
T1	H1	2 750	1/0	14 200	YES	-
T1	H2	2 925	1/0	14 200	YES	-
T1	H3	3 542	1/0	14 200	YES	-
T1	H4	4 514	500	22 700	YES	-
T1	H5	4 551	500	22 700	YES	-
T1	H6	3 335	1/0	14 200	YES	-
T1	H7	3 922	500	22 700	YES	-
T1	CS1	2 529	3/0	22 700	YES	-
T1	CS3	2 297	2	8 891	YES	-
T1	CS4	2 359	2	8 890	YES	-
CS1	H8-10	1 431	6	2 290	YES	-
CS1	CS2	1 579	2	8 890	YES	-
CS2	H11-H13	1 180	2	8 980	YES	-
CS3	H14	429	14	1 430	YES	-
CS3	H15	1 039	6	2 290	YES	-
CS4	H16	554	10	1 430	YES	-
CS4	H17	546	14	1 430	YES	-
CS4	H18	471	14	1 430	YES	-
T2	H19	4 995	500	22 700	YES	-
T2	H20	1 594	6	2 290	YES	-
T2	H46	1 052	10	1 430	YES	-

From	To	Ip [A]	Cable (AWG)	Limit [A]	Ip<Limit?	New Cable
T2	H47	931	10	1 430	YES	-
T2	H48	725	10	1 430	YES	-
T2	H49	1 042	10	1 430	YES	-
T2	H58	752	14	1 430	YES	-
T2	CS5	3 659	500	22 700	YES	-
T2	CS6	3 473	500	22 700	YES	-
T2	CS7	2 971	2/0	14 200	YES	-
T2	CS8	2 735	2/0	14 200	YES	-
CS5	H21,22,26	947	6	2 290	YES	-
CS5	H23-H25	1 366	6	2 290	YES	-
CS5	H27-H29	1 560	6	2 290	YES	-
CS5	H30-H31	922	6	2 290	YES	-
CS6	H32-H34	2 249	6	2 290	YES	-
CS6	H35-H37	1 434	6	2 290	YES	-
CS6	H38-H41	1 739	2	2 290	YES	-
CS6	H42-H45	1 704	6	2 290	YES	-
CS7	H50-H51	740	10	1 430	YES	-
CS7	H52-H53	825	10	1 430	YES	-
CS8	H54-H55	770	10	1 430	YES	-
CS8	H56-H57	804	10	1 430	YES	-

6.5 Simulations - summary

The voltages in the Venezuelan grid were much harder to maintain to their level, i.e. the voltage drops were much larger. Compared to the Swedish grids, where there are an increased voltage on many of the bus bars, see Figures 6.1 and 6.2, the only bus bars with over voltage in the Venezuelan grids are the first bus bars form the transformers, and then there are the severe voltage drops, see Figures 6.3 and 6.4. This may be due to the nominal voltage in the grid. The voltage is almost half as large as in the Swedish voltage, but the transferred power is set to be the same. This causes the current to increase, and therefore also the losses, since $P \propto I^2$. This is also the reason why the losses are larger in the Venezuelan grid than in the Swedish grid.

As seen from the Swedish electrical loading simulations on the high voltage parts, Figure 6.5 and 6.7, the electrical loading on the high voltage cables in the two Swedish grids is very low. This would be a reason to decrease the dimension of the cables, but this has not been done since the two choices of cables in the grids (Mini: AXCEL 3x50, Large: AXCEL 3x95) are standard high voltage cables, and a decrease of the dimension of the cables would not make a significant impact on the costs. The increase of dimension of these cables could be seen as an investment for future purposes.

Over all, the electrical loading on the cables are a little bit higher in the Venezuelan grid, see Figures 6.5 to 6.11. This is also after the cables have been over sized due to the severe voltage drops. An example can be seen in Figures 6.8 and 6.12, where the cable from transformer 1, T1, to House 1 is a N1XE-4x95 cable in the Swedish grid, and a AWG 1/0 cable in the Venezuelan grid. The two cables resistances are quite similar (0,32 and 0,34 Ω/km and the rated current of each cable is also close (170 A, 229 A). Even though the similarities, the electrical loading on the Swedish cable is only 50% and the electrical loading on the Venezuelan cable is 70%. The reason to this may be because of the larger currents in the cables, and also due to the balance of loading in the rest of the grid. In order to decrease the electrical loading, the cable sizes needs to be increased even more. The electrical loading is supposed to be around 60-80% on each cable. The cable from T2 to house 19 is 78%, and would be an example of a cable that could be changed in to a larger one. This has not been done since the cable is only supplying one single house, going straight from the transformer to the house, and the possibility of adding load to the cable is not taken into consideration.

The losses in each grid may seem to be a bit high, see Table 6.1, but since they are all calculated with maximum load, i.e. the worst case scenario, they are acceptable. The difference between the two Swedish grids is quite large. The Mini Grid has the same amount of active losses as the Large Grid, but it only transmits half the power as the Large Grid, and thereby, the losses are twice the size. This due to the sizing of the cables. In the second part of the grid, i.e the grid from transformer 2, the individual loads are increased in the Mini Grid, compared to the Large Grid. But the cables are mostly the same. This causes the current to increase and therefore the losses, according to Ohm's law, see Equation 2.1, Chapter 2.5. In the other part of the grid, after transformer 1, the loads in the Large Grid are much bigger than in the Mini Grid, but here the cables have also been magnified and therefore there are no additional losses. The difference in the two Venezuelan Grids are pretty much the same as in the Swedish Grids. The Mini Grid has almost twice as much active losses as the Large Grid. This can also be seen when comparing the two Large Grids with each other and the two Mini Grids with each other. The Venezuelan grids do both have almost twice as much losses the Swedish Grids. This is due to the decreased voltage and thereby the increased current in the Venezuelan grids. Since $P \propto I^2$, the losses are also increasing due to this decreased voltage. The losses occur because of heat generated in the cables by the increased current and the resistance, according to Equation 2.1.

All calculated short circuit currents were below the given limit of each cable, except in Scenario 2, Swedish grid, Large load profile, see Tables 6.2 to 6.5. In this scenario, there were several currents that exceeded the limit, and all those cables were the same size - N1XV-U5x10. Therefore, all of these cables needed to be changed into one size larger, the N1XV-U5x16 cable, which have a higher limit of short circuit current and can handle the calculated current. The increased short circuit currents, see Table 6.3, may exist due to the change in load in the grid. At these points, the loads have decreased from 6,24 kW (Mini grid load) to 5 kW (Large grid load), but the overall power demand in the system has increased. The cables to these point have not changed in size, and that may have an effect on the short circuit currents.

Since there was no standard break time for the Venezuelan grids, the break time of 0,1 s, as given from the Swedish standards, was used in all scenarios. The same problem occurred with the short circuit current limits in the Venezuelan grid. As explained in Chapter 5.3, the Swedish current limits were applied on the Venezuelan model as well.

Chapter 7

Cost

This chapter will present a cost calculation for each scenario. The Swedish cost calculations have been made through a method developed by ÅF. The Venezuelan cost calculations have been made with help from sources at ÅF and prices from manufacturers.

Presented below are the costs for each country and each scenario, followed by a summary.

7.1 Swedish cost calculation

The Swedish cost calculation model has been developed by ÅF in accordance with the grid companies, based on the EBR cost catalogue, [41]. In order to calculate all excavation parts and the real cable length, the grid was divided into 99 parts exploiting all cables in each part, and then added together.

Explanation of some calculated cost items:

- Line Cu-25 Buried cable-grid: *The length of cable ditch for HV-cables * 1,03 for buckling and an extra 5 m per station*
- Restoration of dirt road/surface extinction: *Length of cable grave for total grid * 1 m, in hectare*
- Restoration of dirt road/surface: *For each crossing of a road, where the road is expected to be 5 m wide, crossings x 5 m*
- N035-N055, 0,5-0,7 Excavation, refill: *0,5-0,7 m refill in the excavation, length of excavation*
- Exchange of masses: *5% of total excavation length. The soil is assumed to be sand or standard earth, and therefore, the amount of exchange is approximated to 5%*

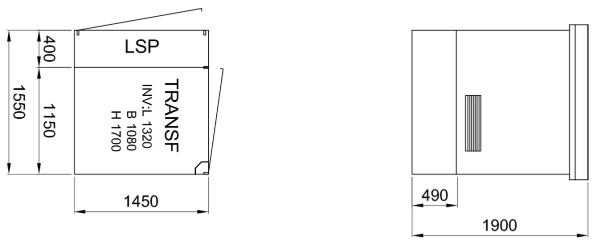
- Packing/0,3m acc. To installation-"AMA": *For each crossing of a road, where the road is expected to be 5 m wide, crossings x 5 m*
- Installation of distance pole: *For long distance cables, here placed by the high voltage cables, to mark the distance*
- Apply splitting pipes around cable in the shaft 3 m (slit) SRN: *For each crossing: crossings x 3 m*
- Splices: *The cables come in sets of 500 m. The lengths need to be matched for each set and for between each set, a splice needs to be installed.*
- Power station: *The distribution station in the middle, FS*
- Satellite station: *the transformer stations. Here set as 200 kVA, but they can manage a much larger transformer*
- 12/0,4 kV – kVA: *Transformers*
- Truck: *The assumed time needed for excavation of the grid*
- Supplementary basic preparation for projects > 1 km: *If the shaft length is longer than 1 km, an extra fee is included*
- Property ownership: *The land is assumed to be owned by one/several people*
- Seek permissions: *Permissions for all buildings*
- Create agreements: *Assumed number of agreements needed*
- Enrolment fee: *As the number of agreements*

Other comments:

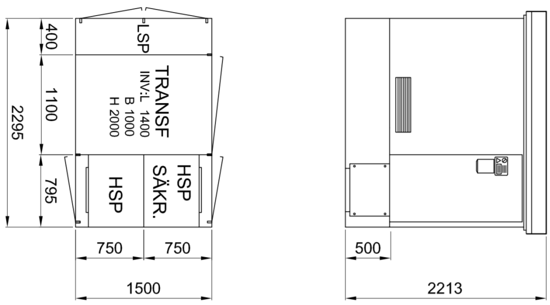
- The cost for these station has not been considered in the calculation.
- The soil is assume to be sand/light earth.
- The roads are assumed to be packed gravel
- No crossing obstacles have been taken into consideration.
- The entire grid is to be buried, by excavation/trenching, not by plowing.
- For each connection to a cable cabinet, an extra 5 m of cable has been added. For a connection to a transformer station or distribution station, an extra 10 m has been added.
- For the high voltage cables an extra splice is often ordered. For the low voltage cables, an extra set of 500 m cable is instead ordered. It is assumed that the cost of the high voltage cables are

quite high, and therefore, it is cheaper to add an extra splice and use all the cable, than to order an extra set of 500 m cable. Regarding the low voltage cables, the situation is different. The cables are relatively cheap, and therefore, an extra set of 500 m cable is often ordered, instead of ordering an extra splice.

- There is no outgoing high voltage cable in this grid, since no storage is included in the simulated model. Therefore, the distribution station only needs to be a simple satellite station, and not a serial satellite station. The simple satellite station does not include an outgoing high voltage connection, as the serial satellite station does. An example of a 315 kVA satellite station and a 315 kVA serial satellite station iar shown in Figure 7.1.



(a) A satellite station



(b) A serial satellite station

Figure 7.1: Two different transformer stations [42]

- The smaller steering cable has been chosen, the EKLR 5x2x1,5. This cable has 10 communication channels, which is assumed to be enough for this grid.
- The low voltage fuses are included in the cable cabinets, and therefore not included in this calculation.

Amount	Unit	Work	Planner	Installer	Machine	Work	Material	Machine	Other	Total
10	st	Earthing	3	12	12	11 060	5 680	8 720	0	25 460
0,841	km	Line Cu25 Earth cable-grid	0	3	3	2 258	13 455	1 804	0	17 517
10	st	Earthing rod	0	1	1	730	1 000	650	0	2 380
10	st	Soil measurement	2	7	0	6 530	0	0	0	6 530
0,2389	ha	Restoration of dirt road/surface extinct	0	0	0	21	11 734	0	1 834	13 589
185	m2	Restoration of dirt road/surface	0	0	2	555	925	1 850	0	3 145
2,396	km	N035-N055 0,5-0,7 Excavation, refill	4	106	141	80 382	11 953	100 751	0	193 087
119	m3	Exchange of earth	1	5	6	3 927	19 516	4 165	13 566	41 174
119	m3	Deposit fee	0	0	0	0	0	0	24 752	24 752
8	st	Excavation and set cable cabinets	6	7	7	10 024	0	5 344	0	15 360
3	st	Excavation, foundation, drain for net s	1	12	12	9 738	12 939	8 751	0	31 431
2,396	km	Sanding 0,3-0,7 m	1	21	37	16 123	29 078	26 212	0	71 413
185	m2	Packing/0,3m acc. To Installation-"AMA	2	11	6	9 990	0	4 440	0	14 430
6	st	Installation of distance pole	0	2	0	1 308	1 962	0	0	3 270
0,102	km	Apply splitting pipes around cable in th	0	2	0	1 277	8 320	0	0	9 597
4,403	km	Extraction/pulling cable <= 1.0 kg/m	4	10	10	10 677	0	7 494	0	18 167
0,991	km	Extraction/pulling cable > 1,0 <= 2,5 k	1	4	4	3 372	0	2 660	0	6 032
0,171	km	Extraction/pulling cable > 2,5 <= 4,5 k	0	1	1	816	0	694	0	1 509
0,837	st	Mantle testing 3-core cable	0	0	0	183	0	0	91	275
1	st	Splice 12-24kV PEX 3x10-50	0	4	0	3 141	1 985	0	0	5 126
6	st	Splice 0,4kV N1XV(E) 10-16	1	2	0	1 830	234	0	0	2 058
6	st	Supplementary splice 5-conductor 0,4	0	1	0	762	414	0	0	1 176
6	st	End 12-24 kV in house PEX 3x50-240	2	16	0	13 344	6 702	0	0	20 046
70	st	Connect cable 0,4kV N1XV(E) 10-50	7	23	0	21 770	1 400	0	0	23 170
2	st	Connect cable 0,4kV N1XV(E) 95-150	0	1	0	1 010	40	0	0	1 050
2	st	Connect cable 0,4kV N1XV(E) 240	0	2	0	1 618	40	0	0	1 658
68	st	Supplementary connect 5-conductor 0,	3	3	0	4 624	0	0	0	4 624
1	st	Splice steering cable EKLR 5x2x1,5	0	0	0	406	227	0	0	634
2,396	km	Survey of cable graves, rural areas	0	10	0	7 437	199	0	1 198	8 834
1	st	Power station N3/3 315 kVA	1	4	0	3 789	99 772	0	10 979	114 540
2	st	Satellite station S2 200 kVA	3	8	0	7 578	77 520	0	21 958	107 056
0,837	km	PEX 3x50	0	0	0	0	51 111	0	0	51 111
3,015	km	N1XV(E) 5x10-CU	0	0	0	0	124 646	0	0	124 646
0,382	km	N1XV(E) 5x16-CU	0	0	0	0	26 214	0	0	26 214
0,169	km	N1XV(E) 4x50	0	0	0	0	4 499	0	0	4 499
0,154	km	N1XV(E) 4x95	0	0	0	0	7 708	0	0	7 708
0,171	km	N1XV(E) 4x240	0	0	0	0	17 497	0	0	17 497
0,837	km	EKLR 5x2x1,5	0	0	0	0	20 880	0	0	20 880
6	st	Cable cabinet K1	0	0	0	0	35 928	0	0	35 928
2	st	Cable cabinet K2	0	0	0	0	17 604	0	0	17 604
1	st	12/0,4 kV 500 kVA	0	0	0	0	74 259	0	0	74 259
1	st	12/0,4 kV 315 kVA	0	0	0	0	52 961	0	0	52 961
1	st	Power station, assembly of sum measu	0	2	0	1 494	5 443	0	0	6 937
1	st	Control of measurement system, LV	1	2	0	2 140	0	0	0	2 140
1	st	Measurement value collection	0	0	0	0	0	0	619	619
4	st	Connection work, HV and LV	0	3	0	2 328	0	0	0	2 328
4	st	Interruption work 12-24 kV	0	6	0	4 120	0	0	0	4 120
2	st	Interruption work 0,4 kV	0	2	0	1 110	0	0	0	1 110
2	st	Startup of network station incl. Markup	0	3	0	1 836	0	0	0	1 836
8	st	Startup of cable cabinets	0	3	0	2 200	0	0	0	2 200
58	st	Startup of new LV-customer	0	20	0	14 964	0	0	0	14 964
80	tim	Truck	1	0	0	560	0	0	49 920	50 480
1	Arb	Cable machine and 2 installers	1	6	3	4 722	0	2 056	0	6 777
1	st	Basic preparation, fixed tiem/project	4	0	0	2 613	0	0	0	2 613
1,396	km	Supplement basic preparation for proje	5	0	0	3 648	0	0	0	3 648
2,396	km	Property ownership management	2	0	0	1 392	0	0	0	1 392
58	st	Seek permissions	58	0	0	42 108	0	0	0	42 108
6	st	Create agreements/contracts	6	0	0	4 356	0	0	0	4 356
6	st	Enrollment fee	0	0	0	0	0	0	2 250	2 250
6	st	HV fuse 12-24 kV	1	0	0	420	9 000	0	0	9 420
8	st	Marking bar cable cabinet	1	2	0	2 240	3 600	0	0	5 840
------		**TOTAL**	**125**	**326**	**244**	**328 531 kr**	**756 445 kr**	**175 591 kr**	**127 167 kr**	**1 387 535 kr**

Figure 7.2: Costs for Swedish Mini Grid

Amount	Unit	Work	Planner	Installer	Machine	Work	Material	Machine	Other	Total
10	st	Earthing	3	12	12	11 060	5 680	8 720	0	25 460
0,841	km	Line Cu25 Earth cable-grid	0	3	3	2 258	13 455	1 804	0	17 517
10	st	Earthing rod	0	1	1	730	1 000	650	0	2 380
10	st	Soil measurement	2	7	0	6 530	0	0	0	6 530
0,2389	ha	Restoration of dirt road/surface extincti	0	0	0	21	11 734	0	1 834	13 589
185	m2	Restoration of dirt road/surface	0	0	2	555	925	1 850	0	3 145
2,396	km	N035-N055 0,5-0,7 Excavation, refill	7	174	231	131 833	19 604	165 240	0	316 679
119	m3	Exchange of earth	1	5	6	3 927	19 516	4 165	13 566	41 174
119	m3	Deposit fee	0	0	0	0	0	0	24 752	24 752
8	st	Shaft and set cable cabinets	6	7	7	10 024	0	5 344	0	15 360
3	st	Excavate, foundation, drain for net stat	1	12	12	9 738	12 939	8 751	0	31 431
2,399	km	Sanding 0,3-0,7 m	1	21	37	16 143	29 114	26 245	0	71 502
185	m2	Packing/0,3m acc. To Installation-"AMA	2	11	6	9 990	0	4 440	0	14 430
6	st	Installation of distance pole	0	2	0	1 308	1 962	0	0	3 270
0,102	km	Apply splitting pipes around cable in th	0	2	0	1 277	8 320	0	0	9 597
3,138	km	Extraction/pulling cable <= 1.0 kg/m	3	7	7	7 610	0	5 341	0	12 947
1,977	km	Extraction/pulling cable > 1,0 <= 2,5 k	2	7	7	6 728	0	5 306	0	12 034
0,484	km	Extraction/pulling cable > 2,5 <= 4,5 k	0	3	3	2 309	0	1 964	0	4 272
0,837	st	Mantle testing 3-core cable	0	0	0	183	0	0	91	275
1	st	Splice 12-24kV PEX 3x95-240	0	4	0	3 141	2 640	0	0	5 781
4	st	Splice 0,4kV N1XV(E) 10-16	0	1	0	1 220	156	0	0	1 372
1	st	Splice 0,4kV N1XV(E) 95-150	0	1	0	569	396	0	0	964
4	st	Supplementary splice 5-conductor 0,4 k	0	1	0	508	276	0	0	784
6	st	End 12-24 kV in house PEX 3x50-240	2	16	0	13 344	6 702	0	0	20 046
59	st	Connect cable 0,4kV N1XV(E) 10-50	6	19	0	18 349	1 180	0	0	19 529
11	st	Connect cable 0,4kV N1XV(E) 95-150	1	7	0	5 555	220	0	0	5 775
4	st	Connect cable 0,4kV N1XV(E) 240	0	4	0	3 236	80	0	0	3 316
50	st	Supplementary connect 5-conductor 0,	3	2	0	3 400	0	0	0	3 400
1	st	Splice steering cable EKLR 5x2x1,5	0	0	0	406	227	0	0	634
2,399	km	Survey of cable graves, rural areas	0	10	0	7 446	199	0	1 200	8 845
1	st	Power station N3/3 315 kVA	1	4	0	3 789	99 772	0	10 979	114 540
1	st	Satellite station S8 800 kVA	1	4	0	4 037	86 682	0	11 002	101 721
1	st	Satellite station S2 200 kVA	1	4	0	3 789	38 760	0	10 979	53 528
0,837	km	PEX 3x95	0	0	0	0	67 596	0	0	67 596
1,942	km	N1XV(E) 5x10-CU	0	0	0	0	80 286	0	0	80 286
0,358	km	N1XV(E) 5x16-CU	0	0	0	0	24 567	0	0	24 567
0,363	km	N1XV(E) 4x50	0	0	0	0	9 664	0	0	9 664
0,7783	km	N1XV(E) 4x95	0	0	0	0	35 497	0	0	35 497
0,4837	km	N1XV(E) 4x240	0	0	0	0	49 492	0	0	49 492
0,837	km	EKLR 5x2x1,5	0	0	0	0	20 880	0	0	20 880
6	st	Cable cabinet K1	0	0	0	0	35 928	0	0	35 928
2	st	Cable cabinet K3	0	0	0	0	22 496	0	0	22 496
1	st	12/0,4 kV 800 kVA	0	0	0	0	90 607	0	0	90 607
1	st	12/0,4 kV 500 kVA	0	0	0	0	74 259	0	0	74 259
1	st	Power station, assembly of sum measu	0	2	0	1 494	5 443	0	0	6 937
1	st	Control of measurement system, LV	1	2	0	2 140	0	0	0	2 140
1	st	Measurement value collection	0	0	0	0	0	0	619	619
4	st	Connection work, HV and LV	0	3	0	2 328	0	0	0	2 328
4	st	Interruption work 12-24 kV	0	6	0	4 120	0	0	0	4 120
2	st	Interruption work 0,4 kV	0	2	0	1 110	0	0	0	1 110
2	st	Startup of network station incl. Markup	0	3	0	1 836	0	0	0	1 836
8	st	Startup of cable cabinets	0	3	0	2 200	0	0	0	2 200
58	st	Startup of new LV-customer	0	20	0	14 964	0	0	0	14 964
80	tim	Truck	1	0	0	560	0	0	49 920	50 480
1	Arb	Cable machine and 2 installers	1	6	3	4 722	0	2 056	0	6 777
1	st	Basic preparation, fixed time/project	4	0	0	2 613	0	0	0	2 613
1,399	km	Supplement basic preparation for proje	5	0	0	3 656	0	0	0	3 656
2,399	km	Property ownership management	2	0	0	1 394	0	0	0	1 394
58	st	Seek permissions	58	0	0	42 108	0	0	0	42 108
6	st	Create agreements/contracts	6	0	0	4 356	0	0	0	4 356
6	st	Enrollment fee	0	0	0	0	0	0	2 250	2 250
6	st	HV fuse 12-24 kV	1	0	0	420	9 000	0	0	9 420
8	st	Marking bar cable cabinet	1	2	0	2 240	3 600	0	0	5 840
------		**TOTAL**	**127**	**400**	**337**	**383 273 kr**	**890 854 kr**	**241 876 kr**	**127 191 kr**	**1 642 999 kr**

Figure 7.3: Costs for Swedish Large Grid

7.2 Venezuelan cost calculation

Accurate costs for the Venezuelan grids are not as easily found as for the Swedish grids. The situation in Venezuela has caused the inflation rate to increase significantly, as in December, the inflation rate reached 800%, [43]. This uncertainty causes the current prices to change rapidly, and according to sources at ÅF, the costs are currently set from the manufacturers, but will be changed every three months.

The Venezuelan cost calculations in this thesis are obtained from an offer made on the Venezuelan Large Grid from contacts in Venezuela. This offer has also been used, but modified, in order to reflect the costs for the Venezuelan Mini Grid. The cable costs for each type of cable are presented individually in Table 7.1, and are in accordance with the costs in the offer. In Table 7.2, the costs for the Large Grid are presented, as different work posts and their total cost in USD and in SEK. The exchange rate from USD to SEK is from [44], 1 USD= 8.81758 SEK. In Table 7.3, the costs for the Mini Grid are presented, based on the costs from the Large Grid.

Cable type (AWG)	**Cost per meter[USD/m]**
10 kV - 2	42
14	8
10	14
6	33
2	89
1/0	28
2/0	34
3/0	42
500	119

Table 7.1: Cable costs, Venezuelan cables

Amount	Unit	Work	Comment	Cost [USD]	Cost [SEK]
3	pcs	Substation	1 DS, 2 HV/LV	19 400	171 061
2	pcs	Transformer	800 kVA, 500 kVA	10 820	95 406
773.5	m	Cable	10 kV AWG 2	32 487	286 457
1 405	m	Cable	AWG 14	11 240	99 110
495.5	m	Cable	AWG 10	6 937	61 168
611.9	m	Cable	AWG 6	20 193	178 053
403.8	m	Cable	AWG 2	35 938	316 886
230.7	m	Cable	AWG 1/0	6 460	56 962
219.9	m	Cable	AWG 2/0	7 477	65 929
231.8	m	Cable	AWG 3/0	9 736	85 848
614.5	m	Cable	AWG 500	73 126	644 794
8	pcs	Cable Cabinets	Type K1 and K3	3 760	33 154
1	-	Earthing	-	2 500	22 044
1	-	Trenching/Excavation	-	5 670	49 996
1	-	Installation/connections	-	2 500	22 044
1	-	Commissioning	-	1 500	13 226
1 -	-	Special tools/machinery	Forklift, machines	2 500	22 044
1	-	Site transportation	Cables, transformers	3 500	30 862
1	-	Private security	-	1 200	10 581
1	-	Permissions	Work permit coordination	600	5 291
1	-	Preparation work	Logistics	1 000	8 818
-	-	**Total cost**	-	**258 544**	**2 279 734**

Table 7.2: Total costs for the Venezuelan Large Grid, made as an offer from Venezuela

The costs for the Mini Grid are based on the costs for the Large Grid, by the offer from Venezuela. The transformer costs were divided into cost/kVAR and then the total cost for 315 kVA + 500 kVA were calculated in this case. The cable costs are previously presented in Table 7.1, and the rest of the costs for Cable cabinets, down to Preparation work are all the same in the two grids.

Amount	Unit	Work	Comment	Cost [USD]	Cost [SEK]
3	pcs	Substation	1 DS, 2 HV/LV	19 400	171 061
2	pcs	Transformer	500 kVA, 315 kVA	6 783	59 812
773.5	m	Cable	10 kV AWG 2	32 487	286 457
1 284.9	m	Cable	AWG 14	10 278	90 638
680.4	m	Cable	AWG 10	9 545	84 163
936.9	m	Cable	AWG 6	30 918	272 623
639.2	m	Cable	AWG 2	56 888	501 619
340	m	Cable	AWG 1/0	9 521	83 949
331.7	m	Cable	AWG 500	39 543	347 883
8	pcs	Cable Cabinets	Type K1 and K3	3 760	33 154
1	-	Earthing	-	2 500	22 044
1	-	Trenching/Excavation	-	5 670	49 996
1	-	Installation/connections	-	2 500	22 044
1	-	Commissioning	-	1 500	13 226
1 -	-	Special tools/machinery	Forklift, machines	2 500	22 044
1	-	Site transportation	Cables, transformers	3 500	30 862
1	-	Private security	-	1 200	10 581
1	-	Permissions	Work permit coordination	600	5 291
1	-	Preparation work	Logistics	1 000	8 818
-	-	**Total cost**	-	**240 093**	**2 116 265**

Table 7.3: Total costs for the Venezuelan Mini Grid, based on the costs for the Large Grid

7.3 Cost calculations - summary

Grid	Total cost [SEK]
Swedish Mini Grid	1 387 535
Swedish Large Grid	1 642 999
Venezuelan Mini Grid	2 116 265
Venezuelan Large Grid	2 278 734

Table 7.4: Summation of the total costs for the four grids

As seen in the Swedish cost calculations, the largest cost items are the excavation and the power stations/satellite station. The total cost difference between the two Swedish grids is only 255,464 SEK, i.e the Large Grid only cost 18 % more than the Mini Grid. This is not a big difference since the total load that the grid is designed for is more than twice the size of the Mini Grid (0,88 MW vs. 0,41 MW). A limited expenditure allows for us to develop a robust solution, but lowest cost and economic advantages need to be weighted against the lifetime of the system.

In the two Venezuelan grids, it can be seen in Tables 7.2 and 7.3 that the largest expenditures are for the cables. The two most expensive cables are the low voltage cables AWG 500 and AWG 2. In the Mini Grid, the AWG 14 is used for a length twice the size as the AWG 2, but it still only costs 1/5 of what the AWG 2 costs. The total costs for the transformers are lower than any of the costs for the cables in the Mini Grid, and in the lower range of costs in the Large Grid. The difference between the two Venezuelan grids is not huge, the Large Grid only costs about 7.68% more than the Mini Grid. This may be due to the usage of the AWG 2 cable in the Mini Grid.

Comparing the cost for the Swedish grids with the cost for the Venezuelan grids, there is a huge difference. The difference is not only within the calculation, where as transformers and trenching play huge parts in the Swedish cost calculation, but in the Venezuelan calculations, the cables are the expensive part. Comparing the costs of the two Mini Grids to each other, see Table 7.4, there is a large difference, as the Venezuelan Mini Grid is almost 1 million SEK more expensive than the Swedish Mini Grid. The Venezuelan Mini Grid costs about 52.5% more than the Swedish Mini grid. The cables costs in the Venezuelan Mini Grid sums up to 1 667 332 SEK, which is more than the entire cost of the Swedish Mini Grid. The difference between the two Large grid as also big, where the Venezuelan Grid costs 39% more than the Swedish Large Grid.

These huge cost differences may be explained by the fact that Venezuela uses copper cables in their grids. Since the cables are the only large cost factors, this could be a big problem, especially since the cable costs increases with increased cable size, and the cables had to be changed into larger ones several times in order to keep the voltage level limits and the electrical loading limits.

Chapter 8

Conclusions and recommendations for further work

8.1 Conclusions

The Venezuelan standards are not as developed as the Swedish ones. There is a severe lack of information, that is, according to the sources at ÅF, instead maintained by experience. This causes problems when trying to design the grid, since there is no indication of maximum short circuit currents, break time or voltage deviation limits. The standards that actually do exists cause the Venezuelan grids to be designed in such way that it demands larger cables then originally calculated for, this in order to maintain the same quality as the Swedish grids. The lack of standards in the country may be replaced by applying standards from another country, for example USA, and that would definitely help a lot. Many reports and articles point out the fact that the electrical system has not been serviced since it was first built and that it has not been adjusted to the growing energy demand in the country. If the country would have had better and more developed standards, this may not have been such a big problem. Developing new, and updating old standards could help the country creating a united, functioning and reliable grid, and eliminating the occurring power outages and other problems. The standards in the Código Eléctrico Nacional, [32], include a lot of specifics for machines and special circumstances, but the standards for the normal cases seems to be neglected. This lack of standards, combined with the severe drought in the country, may be partly responsible for the lack of generated power and also for the unstable grid which in turn are causing the constant outages experienced recently in the country.

The Swedish standards are well developed and are updated frequently in order to keep up with the new technology. Regarding Swedish standards applied on an islanded micro grid, the development is ongoing. As it is right now, some of the standards are adjusted when applied on an islanded grid, but it could definitely be beneficial with more tailored standards. The existing standards may be a bit too harsh for an islanded micro grid, since no impact of different disturbances will be seen on the main grid. The standards are good and will assure a stable and functioning grid, but the demands might be lowered, in order to also lower the costs and availability.

A remarkable fact is that the cables used in Venezuela are mainly copper cables. Although the material's conductivity is large, the cost of the cables has made many other countries to chose aluminium cables instead. The copper cables increase the cost significantly, and the cable costs play a large part in the total cost of the Venezuelan grid, compared to the cables in the Swedish grids. A difference between the Swedish and the Venezuelan cables is also that the minimum size used in Sweden is 10 mm^2. This is a lot larger than the minimum cable size in Venezuela, which is 14 AWG = 2,08 mm^2. When having set this minimum size in Sweden, it could be a risk of over-sizing of the system, but also, since the cable costs in Sweden are relatively low, this possible over-sizing does not seem to be a problem, instead it assures a better quality and lower losses.

As seen in the simulations, the losses in the Venezuelan grid were sometimes twice as big as the losses in the Swedish grids, even when having increase the dimensions of the cables with 25% from the beginning. Despite this initial increase, the cable sizes needed to be increased again several times in order to minimise the voltage drop and the losses. This in turn increases the costs for the cables, since the cost increases with the cable size, and the small cable sizes seem even more unnecessary. This is also a problem for the appliances that require specific voltage level. A decreased voltage supply decrease the quality and the functionality of the devices and in some cases they may case failure or damage.

The simulations clearly shows that the problem with the Venezuelan grid lays with the voltage. Since the voltage is almost half the Swedish voltage (127 V vs. 230 V), the current is increasing correspondingly in order to transfer the same power. This is a problem that is not so easy to change, and a change in the standards would not help this problem. The voltage level is set and changing the voltage would require a change in all systems, in all appliances and machines that are built for the old voltage. This is a problem that can not be solved by voltage standards, but maybe changes in other standards can help to minimise losses and voltage deviation in other ways.

The cost calculations made based on EBR (Sweden) and from an offer on the Venezuelan Large Grid, shows that the Venezuelan cables are very expensive. The fact that the conducting material is copper may be the reason to this. The transformers and the trenching/excavation that were the expensive part in the Swedish grids played a small part in the Venezuelan calculations. Also, the trenching cost seem to be a combined, fixed cost, and not in cost per length as in Sweden, this is a difficult factor to consider. Regarding the cable costs, the most expensive Venezuelan cables were the AWG 2 and AWG 500. Since the AWG 500 is the largest cable used in this thesis, it can be assumed to be the most expensive one, but there is no indication of why the AWG 2 is so expensive. The costs for this cable definitely increases the total cost a lot, and it could be a reason to change cable to a larger, but cheaper, one.

The difference in cost between the two Swedish grids and between the two Venezuelan grids is not big. The amount of power is doubled in the Large grids, but the total costs are only increased by 18% (Sweden) and 7% (Venezuela). In order to actually get a significant increase in costs, a large size of transformers would be needed, and thereby a large increase in power. In this range of transmitted power, the difference is almost negligible, and a reason for building as the Large Grids could be to aim for a stable and secure grid with room for future expansion. On the other hand, if the aim is to minimise the costs, and if there is a knowledge of no future expansion, the design of the Mini Grids would be the choice.

From a Swedish company's point of view, going in to the market in Venezuela could be an option if looking at the economical differences. The gap in cost between the Venezuelan and the Swedish grids could be very beneficial to the Swedish companies. The question would be how to adopt to the Venezuelan standards, or if to do so, and what that would do to the total cost of the grids. Since the large costs of the Venezuelan grids were the cable costs, an option could be to adopt to Venezuelan standards, but with Swedish cable structures, modified for the right voltage etc. Just by changing the the copper cables to aluminium cables could do a huge difference to the prices in Venezuela.

This clearly point out the importance of well developed standards, and the usage of them. If Swedish companies are to utilise their know-how and enter the energy market in Venezuela, extensive research would be needed in order to get a total picture of the market. A choice of whether adjusting to Venezuela's standards and way of designing a grid or if going with Sweden's own standards would have to be made. If adjusting to Venezuela's standards - and lack of them - the quality and functionality of the work provided by a company would maybe harmed.

8.2 Recommendations for further work

Whilst this work has shed some light on certain aspects of the energy and more pointedly, the electrical system and standards, for a company to seriously pursue markets internationally, more extensive research about standards involved when designing, constructing and maintaining a grid would be needed. Also more extensive research about the cost and the development of these, especially for the foreign country, is needed.

Another point to consider and explore would be the AC or DC question. More and more standards are being developed concerning DC solutions and a research about the future of DC grids in developing countries would be of great interest. This could also be a part of the development of a plan for how developing countries can be adjusted to the international standards and how the grid development in these countries should be performed. As mentioned, this is currently happening in India, where they are working with 48 V DC grids for residential homes.

A more extensive research about Venezuela could also be important. Since the country is in need of better energy solutions, and maybe a main grid refurbishment, an investment in research of the country's energy systems could open up several new business opportunities.

Over all, old standards are being updated all the time, but the real work tends to be within development of new standards regarding new technologies. For example regarding DC grids and solar panels, and an example could be the development for smart grids standards, where the goal has consciously been to develop standards for the future. The importance of standards for these technologies is huge and especially when interconnecting them into the existing and functioning electrical system today. Countries without functioning infrastructure may find it easier to adapt a well developed system of standards from international sources and implement them as they are, thus possibly reducing the effort required to redesign their own systems.

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Appendices

Appendix A

Swedish standards

A.1 SS 436 40 00 - Low-voltage electrical installations

Execution of electrical installations on a low voltage network.

- 131.5 Protection against fault currents

  Other conductors then live conductors and any other part designated to carry fault currents shall be able to carry the fault current without reaching a harmful temperature.

- 132.6 Conductor area:

  The conductor area shall be determined considering:

  a) the highest temperature of the conductor

  b) acceptable voltage drop

  c) electro-mechanical strains, which the conductors can be exposed to during a short circuit fault.

  d) other mechanical strains

  e) the highest impedance, considering the function of the short circuit protection and the fault protection

- 311.1 In order to obtain an economic and reliable embodiment of an installation, within given limits of temperature and voltage drop, it is important that a maximum load capacity is calculated.

- 311.2 When deciding the maximum load capacity of an installation or part of a installation, the combined power has to be considered.

- 313.11 The following characteristics of the power supply or supplies needs to be determined:

- current type and frequency

- rated voltage

- expected short circuit current by the connection point

- appropriateness with regard to the installation settings, including maximum load capacity

A.2 SS 421 05 01 - IEC Standard voltages

- Voltage: The area 100 V - 1000 V

  For alternating current systems with the rated voltage from 100 V to 1000 V and the associated equipment, the values in Table A.1 are used. The table includes one phase circuits (extensions, feeders etc.) connected to a three phase four-conductor system. The lower values rates the voltage to the neutral conductor and the higher value rated the voltage between the phases. Three-phase systems with the rated voltage 400/690 V is only intended for heavy industrial systems or likewise.

  Table A.1: 100 V - 1000 V

The rated voltage V
230/400
400/690

- Voltage: The area 1 kV - 800 kV

  For three phase alternating current grids with the design voltage 1 kV - 800 kV and the associated equipment, the values in Table A.2 are used The values rates the main voltage.

Table A.2: 1 kV to 800 kV

Design voltage kV	Rated voltage kV
3,6 1)	3,3 1)
7,2 1)	6,6 1)
12	11
24	22
36	33
52	45
72,5	66
145	132
245	220
420	-
800	-

1) These voltages are for industrial use only and not for general distribution grids.

The highest and lowest operating voltage is usually not deviating more than 10% from the rated value. The design voltages (resp. rated voltages) 84 kV (77), 123 kV (110), and 170 kV (150) occurs to some extent in Sweden but will not be recommended for new grids. For Swedish grids, the designations 400, 200, 150, 130, 100, 70, 50, 40, 30, 20, 10, 6 and 3 kV are often used. As default voltage, the values in the table are used.

A.3 SS-EN 50160 - Voltage characteristics of electricity supplied by public electricity networks

- Properties when distributing low and medium voltages

  The standardised rated voltage U_n used for low voltage grids for general distribution is $U_n = 230V$, either between phase and neutral conductors, or between the phase conductors.

- Grid frequency

  The rated frequency of the supply voltage should be 50 Hz. During normal operating conditions, the average of the base tone frequency, measured during 10 s, should be within:

- for a system with a synchronous connection to a main grid: 50 Hz ±1%, (49.5-50.5 Hz), during 99.5% of a year, or
- for a system without a synchronous connection to a main grid (for example grid on islands): 50 Hz ±2%, (49-51 Hz), during 95% of a week.

- Demands

  During normal operating conditions, with the exception of power failure, the voltage variations should not exceed ±10% of the rated voltage U_n. When electricity supply of an area which is not in an interconnected mode, or is located in an remote area, the voltage variations should not exceed $+10\%/-15\%$ of U_n. The end users should then be informed. The same limits apply to medium voltage systems (1 kV - 36 kV) as well.

A.4 SEK Handbok 429 - Cable laying in ground

- Sheathing material:

  As a first hand choice regarding sheathing materials, PE should be chosen because it is harder than PVC and it has better environmental characteristics. The PVC sheathing, or other sheathing which has the right fire classifications, can be chosen for longer indoor distances.

- Conducting material:

  Aluminium is the most common conducting material and is above all used when the cable area exceeds 16 mm^2.

- Cable area:

  The following standardised areas are recommended:

  0,4 kV: 10Cu, 16cu, 16Al, 25Al, 50Al, 95Al, 150Al and 240 Al mm^2.

  12/24 kV: 10Cu, 25Al, 50Al, 95Al, 150A and 240 Al mm^2.

  > 24 kV: Area needed.

A.5 SS 424 17 01 - Power, control and house wiring cables - National designations (Swedish)

The following letter designation for cables are used, [45]:

Figure A.1: Letter designation for cables, according to SS 424 17 01

Bokstav	Första bokstaven Ledare	Andra bokstaven Isolering	Tredje bokstaven Mantel eller annan konstruktionsdetalj	Fjärde bokstaven Konstruktionsdetalj eller användning	Femte bokstaven Konstruktionsdetalj eller användning
A	Aluminium		Skärm av aluminiumfolie		
B	Aluminiumlegering	Flamskyddad termoplastisk polyolefin (halogenfri, låg rök)	Flamskyddad termoplastisk polyolefin (halogenfri, låg rök) Blymantel	Fordonskabel Förbindningstråd Blymantel	
C		Impregnerat papper	Koncentrisk koppartrådskärm	Koncentrisk kopparskärm	
D		Gummi med yttre gummimantel			
E	Koppar, entrådig (klass 1)	Etepropengummi		Förstärkt utförande	Förstärkt utförande
F	Koppar, fåtrådig (klass 2)		Fläta av koppartråd	Fläta av koppar- eller ståltråd	
H		Silikongummi		Hisskabel	Hängkabel
I		Uretanplast	Uretanplast		
J	Ståltråd		Armering av stålband	Förläggning i mark	
K		PVC	PVC	PVC	PVC
L		Polyeten (PE)	Skärm av plastbelagt aluminiumband ev tillsammans med kopparskärm Polyeten (PE)	PE	PE
M	Koppar, fåtrådig				
O		Kloropengummi	Kloropengummi		Oljekabel
P			Armering av förzinkat stålband	Armering av förzinkat stålband	
R	Koppar, mångtrådig (klass 5)		Armering av plastbelagt aluminiumband	Styrkabel	
S	Koppar, fintrådig (klass 6)			Självbärande	
T	Koppar, extra fintrådig	Fluorplast	Armering av ståltråd	Tung anslutningskabel eller armering av ståltråd	Armering av ståltråd
U			Saknar yttre mantel		
V		Gummi utan yttermantel	Etenpropengummi	Förläggning i vatten	Förläggning i vatten
X		Tvärbunden polyeten (PEX)	PVC, ovalt tvärsnitt		
Z		Flamskyddad tvärbunden polyolefin (halogenfri, låg rök)	Flamskyddad tvärbunden polyolefin (halogenfri, låg rök)	Kabel för neonanläggning	

A.6 SS 424 14 24 - Power cables - choice of cables with rated voltage max 0,6/1,0 kV

Rated current value of a single pipe in ground or PVC/PEX isolated cable laid directly in ground, with three loaded phase conductors with a surrounding temperature of 20°C, [40].

Figure A.2: Rated current value of conductors, according to SS 424 14 24

Nominell tvärsnitts-area för ledare, mm²	Förläggningssätt D1, kablar i rör i mark 				Förläggningssätt D2, kablar direkt i mark 			
Ledartemp.	70°C (PVC-isol.)		90°C (PEX-isol.)		70°C (PVC-isol.)		90°C (PEX-isol.)	
	Cu	Al	Cu	Al	Cu	Al	Cu	Al
1,5	18 (21)	-	22 (26)	-	20 (27)	-	23 (32)	-
2,5	24 (28)	18,5 (22)	29 (34)	22 (26)	26 (36)	-	30 (42)	-
4	31 (37)	24 (28)	37 (44)	29 (34)	24 (46)	-	39 (54)	-
6	39 (46)	30 (35)	46 (54)	36 (43)	42 (58)	-	48 (67)	-
10	52 (61)	40 (47)	61 (72)	47 (56)	55 (76)	-	63 (90)	-
16	67 (79)	52 (61)	79 (93)	61 (72)	71 (99)	-	82 (118)	(92)*
25	86 (102)	66 (78)	101 (119)	78 (92)	91 (129)	71 (100)	105 (152)	82 (118)
35	103 (122)	80 (94)	122 (144)	94 (111)	109 (156)	85 (121)	126 (184)	98 (143)
50	122 (144)	94 (111)	144 (170)	112 (132)	129 (185)	100 (144)	149 (218)	116 (169)
70	151 (178)	117 (138)	178 (210)	138 (163)	158 (228)	123 (177)	182 (268)	142 (208)
95	179 (211)	138 (163)	211 (249)	164 (194)	190 (275)	147 (213)	220 (324)	170 (250)
120	203 (240)	157 (185)	240 (283)	186 (220)	216 (315)	168 (244)	250 (369)	194 (286)
150	230 (271)	178 (210)	271 (320)	210 (248)	243 (353)	188 (273)	281 (414)	217 (320)
185	258 (304)	200 (236)	304 (359)	236 (279)	276 (402)	214 (312)	319 (472)	247 (365)
240	297 (351)	230 (271)	351 (414)	272 (321)	321 (465)	247 (359)	371 (547)	286 (421)
300	336 (397)	260 (307)	396 (467)	308 (363)	366 (533)	282 (410)	424 (626)	326 (482)

ANM 1 – Förläggningssätt D1 och D2 avser runda ledare upp till och med 16 mm². Värden för större areor hänför sig till sektorformade ledare och kan med säkerhetsmariginal användas även för runda ledare.

ANM 2 – Strömvärde vid termisk markresistivitet 2,5 K • m/W.
Värdet inom parentes är strömvärde vid termisk markresistivitet 1,0 K • m/W.

* Ingår inte i SS 424 14 24.

Maximum allowed current in Ampere, during 1 s, for 1 kV PEX isolated cable, [40].

Figure A.3: Maximum allowed current during 1 second.

Ledararea, mm²	Ledare av koppar, Begynnelsetemperatur				Ledare av aluminium, Begynnelsetemperatur			
	35 °C	50 °C	70 °C	90 °C	35 °C	50 °C	70 °C	90 °C
1,5	259	247	231	214	-	-	-	-
2,5	432	412	385	357	-	-	-	-
4	692	659	616	572	-	-	-	-
6	1040	989	924	858	-	-	-	-
10	1730	1650	1540	1430	-	-	-	-
16	2770	2640	2460	2290	1830	1740	1630	1510
25	4330	4120	3850	3580	2680	2720	2540	2360
35	6060	5770	5390	5010	4000	3810	3560	3310
50	8650	8250	7700	7150	5720	5450	5090	4720
70	12100	11500	10800	10000	8010	7630	7120	6610
95	16400	15700	14600	13600	10900	10400	9660	8980
120	20800	19800	18500	17200	13700	13100	12200	11300
150	26000	24700	23100	21500	17200	16300	15300	14200
185	32000	30500	28500	26500	21200	20200	18800	17500
240	41500	39600	37000	34300	27500	26100	24400	22700
300	51900	49500	46200	42900	34300	32700	30500	28300
400	69200	66000	61600	57200	45800	43600	40700	37800
500	86500	82500	77000	71500	57200	54500	50900	47200
630	109000	104000	97000	90100	72100	68600	64100	59500
800	138000	132000	123000	114000	91500	87200	81400	75600
1000	173000	165000	154000	143000	114000	109000	102000	94500
1200	208000	198000	185000	172000	137000	131000	122000	113000

A.7 SS-EN 60228 - Conductor of insulated cables

Conductor resistance, 20°C, in (Ω)/km, [40].

Figure A.4: Conductor resistance, according to SS-EN 60228

	Förtent koppartråd		Blank koppartråd		Al-ledare
Ledararea, mm²	Klass 1 + 2	Klass 5 + 6	Klass 1 + 2	Klass 5 + 6	Klass 2
0,5	36,7	40,1	36	39	-
0,75	24,8	26,7	24,5	26	-
1	18,2	20	18,1	19,5	-
1,5	12,2	13,7	12,1	13,3	-
2,5	7,56	8,21	7,41	7,98	-
4	4,7	5,09	4,61	4,95	7,41
6	3,11	3,39	3,08	3,3	4,61
10	1,84	1,95	1,83	1,91	3,08
16	1,16	1,24	1,15	1,21	1,91
25	0,734	0,795	0,727	0,78	1,20
35	0,529	0,565	0,524	0,554	0,868
50	0,391	0,393	0,387	0,386	0,641
70	0,27	0,277	0,268	0,272	0,443
95	0,195	0,21	0,193	0,206	0,320
120	0,154	0,164	0,153	0,161	0,253
150	0,126	0,132	0,124	0,129	0,206
185	0,1	0,108	0,0991	0,106	0,164
240	0,0762	0,0817	0,0754	0,0801	0,125
300	0,0607	0,0654	0,0601	0,0641	0,100
400	0,0475	0,0495	0,047	0,0486	0,0778
500	0,0369	0,0391	0,0366	0,0384	0,0605
630					0,0469

A.8 SEK Handbok 438, SS 421 01 01, grids with rated voltage > 1 kV AC

- The nominal short circuit time is 1,0 s.

A.9 SEK Handbok 449

- Fault in TN-system

  When a fault occurs, the supply should be automatically disconnected after the times in Table A.3. (Only for objects with a supply (group cable) of ≤ 32 A)

Table A.3: Disconnection time when a fault

Phase voltage	Maximum disconnection time
120 V < U_0 <= 230 V	0,4 s
230 V < U_0 <= 400 V	0,2 s
U_0 > 400 V	0,1 s

For objects with a supply of > 32 A, a disconnection time of <= 5 s is allowed.

- Fault in IT-system

  When a single fault, to exposed part of ground, the fault current will be low and the disconnection is therefore not indispensable, provided that the contact voltage towards the locally grounded exposed part isn't dangerous. In case of two faults at the same time, one different phase conductors, the same disconnection times as for TN-systems are acting.

Appendix B

Venezuelan standards

B.1 90 Introduction

90.1 Purpose.
(C) Intention. This Code is not intended to serve as a design specification or as an instruction manual for untrained personnel.
(D) Relation to international standards. The requirements set forth in this code address the fundamental safety principles contained in Section 131 of the International Standard IEC 60364-1, Electrical Installations of Buildings.

B.2 Definition, Rated voltage

- Rated voltage (Voltage, Nominal):
  The nominal value of the voltage is assigned to the circuit of system depending on the its class of tension. 120/240 V, 480 Y /277 V, 600 V etc. The actual operation voltage of the circuit may vary within a band that allows the functionality of the equipment.

B.3 Section 110 Requirements for electrical installations

- Conductors:
  The material of the conductors normally used is copper, unless another material if specified in this code. When the material is unknown, it is referred to as copper.

B.4 Section 110.6 Conductor size

The size of the conductors is expressed in AWG (American Wire Gage)

B.5 Section 110.7 Integrity of the isolation

The wiring must be installed so that the complete system is free from short circuits and grounding, except those permitted in Section 250.

B.6 Section 210.19 Conductors, minimum impedance and size

- (A) Circuit with voltage up to 600 V:
  The branch circuits should have a capacity higher or equal to the maximum load. When a branch circuit feeds continuous loads or any combination of continuous and non-continuous loads, the minimum size of the branch circuit conductor, before applying any adjustment by correction factors, will have a capacity not less than the non-continuous load plus 125% of the continuous load.
- (B) Circuits with voltage greater than 600 V:
  The conductors of the branch circuits above 600 V shall be dimensioned according to 210.19 (B) (1) or (B2).
  (1) General Provisions. The capacity of the branch circuit conductors shall not be less than 125 per cent of the designed potential load of the utilisation equipment which shall operate simultaneously.
  (2) Supervised facilities. For supervised installations, the size of the branch circuit conductors shall be allowed to be defined by qualified personnel under engineering supervision. A supervised installation is defined as that section of a plant where the following aspects are fulfilled:
  (1) Design and construction conditions have been provided under engineering supervision.
  (2) Qualified personnel with training, experience, monitoring and operation antecedents will be in charge of systems with voltages higher than 600 V.

B.7 Section 230.22 Insulation or coating

- Individual conductors shall be insulated or coated.

B.8 Section 230.31 Gauge and current capacity

- (A) General provisions:
  The conductors of the outer ground connection shall be of sufficient capacity to serve the load and shall have adequate mechanical strength.

B.9 Section 230.208 Protection requirements

On the loading side of the disconnection device, there will be a short-circuit protection device whose function is to protect all the active conductors depending on it. The protection device shall be capable of detecting and disrupting all current values that exceed its trigger setting or melting point that may occur at its location. The required short-circuit protection is considered to be met if a fuse is used whose continuous value of its rated capacity is not more than three times the current capacity of the conductor or if a circuit breaker with trip setting of no more than six times the current capacity of the conductors.

B.10 Section 310 Conductors for general wiring

- 310.2 Conductors
  (A) Isolation. Conductors will be isolated. Exception: When specifically covered or naked drivers are allowed in this Code.
  (B) Conductor Material. If not otherwise specified, the conductors referred to in this Section shall be of aluminium, aluminium covered with copper or copper.
- 310.4 Parallel conductors
  Conductors made of aluminium, copper or copper coated aluminium of 1/0 AWG and larger, which are phase conductors, neutral or grounded conductor of a circuit, may be connected in parallel (electrically connected at both ends to form a single conductor).
- 310.5 Minimum gauge of the conductors. The minimum size of the conductors shall be as indicated in table B.1.
- 310.10 Conductor temperature limits
  No conductor shall be used so that its operating temperature exceeds that intended for the type of insulated conductor to which it belongs. In no case shall the conductors be combined

Table B.1: Minimum size of conductors (AWG)

Voltage	**Copper**	**Aluminium or copper pleated aluminium**
0 -2 000	14	12
2 001 - 8 000	8	8
8 001 - 15 000	2	2
15 001 - 28 000	1	1
28 001 - 35 000	1/0	1/0

so that, with respect to the type of circuit, applied wiring method or number of conductors, the temperature limit of any conductor is exceeded.

Appendix C

Cable calculations

C.1 Cable calculations Swedish Mini grid

Voltage	From	To	Type	Length [m]	Real length [+10 m+3%]	[kW]	[kVA]	Current [A]	Cable (I-calc)	New cable (V-drop)	New cable (Ip-calc)
10000	PV	FS	-	257	275	300	352,9	20,4	AXCEL 3*50/16	-	-
10000	Hydro	FS	-	192	208,1	114,21	134,4	7,8	AXCEL 3*50/16	-	-
10000	FS	T1	-	128	142,1	153,59	180,7	10,4	AXCEL 3*50/16	-	-
10000	FS	T2	-	134	148,3	260,62	306,6	17,7	AXCEL 3*50/16	-	-
400	T1	H1	M	83	95,8	10,154	11,9	17,2	N1XE-U5x10	-	-
400	KS1	H10	S	17,5	28,3	6,2362	7,3	10,6	N1XE-U5x10	-	-
400	KS2	H11	S	31	42,2	6,2362	7,3	10,6	N1XE-U5x10	-	-
400	KS2	H12	S	62	74,2	6,2362	7,3	10,6	N1XE-U5x10	-	-
400	KS2	H13	S	17,5	28,3	6,2362	7,3	10,6	N1XE-U5x10	-	-
400	KS3	H14	S	30	41,2	6,2362	7,3	10,6	N1XE-U5x10	-	-
400	KS3	H15	M	62	74,2	10,154	11,9	17,2	N1XE-U5x10	-	-
400	T1	KS1	-	155	170	37,417	44	63,5	N1XE-U5x16	N1XE-A4x50	-
400	T1	KS3	-	77	89,6	16,39	19,3	27,8	N1XE-U5x10	-	-
400	T1	KS4	-	73	85,5	18,709	22	31,8	N1XE-U5x10	-	-
400	T2	KS5	-	139	153,5	68,598	80,7	116,5	N1XE-A4x95	-	-
400	T2	KS6	-	163	178,2	87,306	102,7	148,3	N1XE-A4x95	N1XE-A4x240	-
400	T2	KS7	-	87,5	100,4	24,945	29,3	42,4	N1XE-U5x10	-	-
400	T2	KS8	-	106	119,5	24,945	29,3	42,4	N1XE-U5x10	-	-
400	KS4	H16	S	64	76,2	6,2362	7,3	10,6	N1XE-U5x10	-	-
400	KS4	H17	S	20	30,9	6,2362	7,3	10,6	N1XE-U5x10	-	-
400	KS4	H18	S	26	37,1	6,2362	7,3	10,6	N1XE-U5x10	-	-
400	T2	H19	L	16,5	27,3	13,488	15,9	22,9	N1XE-U5x10	-	-
400	T1	H2	M	70	82,4	10,154	11,9	17,2	N1XE-U5x10	-	-
400	T2	H20	M	52,5	64,4	10,154	11,9	17,2	N1XE-U5x10	-	-
400	KS5	H21	S	99	112,3	6,2362	7,3	10,6	N1XE-U5x10	-	-
400	KS5	H22	S	72	84,5	6,2362	7,3	10,6	N1XE-U5x10	-	-
400	KS5	H23	S	55	67	6,2362	7,3	10,6	N1XE-U5x10	-	-
400	KS5	H24	S	36,5	47,9	6,2362	7,3	10,6	N1XE-U5x10	-	-
400	KS1	KS2	-	72	84,5	18,709	22	31,8	N1XE-U5x10	N1XE-U5x16	-
400	KS5	H25	S	11,5	22,1	6,2362	7,3	10,6	N1XE-U5x10	-	-
400	KS5	H26	S	96	109,2	6,2362	7,3	10,6	N1XE-U5x10	-	-
400	KS5	H27	S	42	53,6	6,2362	7,3	10,6	N1XE-U5x10	-	-
400	KS5	H28	S	37	48,4	6,2362	7,3	10,6	N1XE-U5x10	-	-
400	KS5	H29	S	26	37,1	6,2362	7,3	10,6	N1XE-U5x10	-	-
400	T1	H3	M	41	52,5	10,154	11,9	17,2	N1XE-U5x10	-	-
400	KS5	H30	S	103	116,4	6,2362	7,3	10,6	N1XE-U5x10	-	-
400	KS5	H31	S	82,5	95,3	6,2362	7,3	10,6	N1XE-U5x10	-	-
400	KS6	H32	S	6,5	17	6,2362	7,3	10,6	N1XE-U5x10	-	-
400	KS6	H33	S	7	17,5	6,2362	7,3	10,6	N1XE-U5x10	-	-
400	KS6	H34	S	11,5	22,1	6,2362	7,3	10,6	N1XE-U5x10	-	-
400	KS6	H35	S	48	59,7	6,2362	7,3	10,6	N1XE-U5x10	-	-
400	KS6	H36	S	42	53,6	6,2362	7,3	10,6	N1XE-U5x10	-	-
400	KS6	H37	S	28	39,1	6,2362	7,3	10,6	N1XE-U5x10	-	-
400	KS6	H38	S	17	27,8	6,2362	7,3	10,6	N1XE-U5x10	-	-
400	KS6	H39	S	89	102	6,2362	7,3	10,6	N1XE-U5x10	-	-
400	T1	H4	L	55	67	13,488	15,9	22,9	N1XE-U5x10	-	-
400	KS6	H40	S	50	61,8	6,2362	7,3	10,6	N1XE-U5x10	-	-
400	KS6	H41	S	26	37,1	6,2362	7,3	10,6	N1XE-U5x10	-	-
400	KS6	H42	S	80,5	93,2	6,2362	7,3	10,6	N1XE-U5x10	-	-
400	KS6	H43	S	63,5	75,7	6,2362	7,3	10,6	N1XE-U5x10	-	-
400	KS6	H44	S	47	58,7	6,2362	7,3	10,6	N1XE-U5x10	-	-
400	KS6	H45	S	28	39,1	6,2362	7,3	10,6	N1XE-U5x10	-	-
400	T2	H46	S	33	44,3	6,2362	7,3	10,6	N1XE-U5x10	-	-
400	T2	H47	S	39,5	51	6,2362	7,3	10,6	N1XE-U5x10	-	-
400	T2	H48	S	55,5	67,5	6,2362	7,3	10,6	N1XE-U5x10	-	-
400	T2	H49	S	33,5	44,8	6,2362	7,3	10,6	N1XE-U5x10	-	-
400	T1	H5	L	52	63,9	13,488	15,9	22,9	N1XE-U5x10	-	-
400	KS7	H50	S	45,5	57,2	6,2362	7,3	10,6	N1XE-U5x10	-	-
400	KS7	H51	S	34	45,3	6,2362	7,3	10,6	N1XE-U5x10	-	-
400	KS7	H52	S	38	49,4	6,2362	7,3	10,6	N1XE-U5x10	-	-
400	KS7	H53	S	10,5	21,1	6,2362	7,3	10,6	N1XE-U5x10	-	-
400	KS8	H54	S	43,5	55,1	6,2362	7,3	10,6	N1XE-U5x10	-	-
400	KS8	H55	S	29,5	40,7	6,2362	7,3	10,6	N1XE-U5x10	-	-
400	KS8	H56	S	38,5	50	6,2362	7,3	10,6	N1XE-U5x10	-	-
400	KS8	H57	S	28	39,1	6,2362	7,3	10,6	N1XE-U5x10	-	-
400	T2	H58	S	15	25,8	6,2362	7,3	10,6	N1XE-U5x10	-	-
400	T1	H6	M	50	61,8	10,154	11,9	17,2	N1XE-U5x10	-	-
400	T1	H7	L	111	124,6	13,488	15,9	22,9	N1XE-U5x10	-	-
400	KS1	H8	S	33	44,3	6,2362	7,3	10,6	N1XE-U5x10	-	-
400	KS1	H9	S	15	25,8	6,2362	7,3	10,6	N1XE-U5x10	-	-

Figure C.1: Cable calculations of Swedish Mini grid

C.2 Cable calculations Swedish Large grid

Voltage	From	To	Type	Length [m]	Real length [+10 m+3%]	[kW]	[kVA]	Current [A]	Cable (I-calc)	New cable (V-drop)	New Cable (Ip-calc)
10000	PV	FS	-	257	275	800	941,2	54,3	AXCEL 3*95	-	-
10000	Hydro	FS	-	192	208,1	80	94,1	5,4	AXCEL 3*95	-	-
10000	FS	T1	-	128	142,1	570	670,6	38,7	AXCEL 3*95	-	-
10000	FS	T2	-	134	148,3	310	364,7	21,1	AXCEL 3*95	-	-
400	T1	H1	M	83	95,8	50	58,8	84,9	N1XE-A4x95	-	-
400	KS1	H10	XS	17,5	28,3	5	5,9	8,5	N1XE-U5x10	-	-
400	KS2	H11	XS	31	42,2	5	5,9	8,5	N1XE-U5x10	-	-
400	KS2	H12	XS	62	74,2	5	5,9	8,5	N1XE-U5x10	-	-
400	KS2	H13	XS	17,5	28,3	5	5,9	8,5	N1XE-U5x10	-	-
400	KS3	H14	XS	30	41,2	5	5,9	8,5	N1XE-U5x10	-	N1XE-U5x16
400	KS3	H15	S	62	74,2	20	23,5	34	N1XE-U5x10	-	-
400	T1	KS1	-	155	170	30	35,3	50,9	N1XE-A4x95	-	-
400	T1	KS3	-	77	89,6	25	29,4	42,5	N1XE-A4x95	-	-
400	T1	KS4	-	73	85,5	15	17,6	25,5	N1XE-A4x50	-	-
400	T2	KS5	-	139	153,5	55	64,7	93,4	N1XE-A4x95	-	-
400	T2	KS6	-	163	178,2	70	82,4	118,9	N1XE-A4x240	-	-
400	T2	KS7	-	87,5	100,4	20	23,5	34	N1XE-A4x50	-	-
400	T2	KS8	-	106	119,5	20	23,5	34	N1XE-A4x50	-	-
400	KS4	H16	XS	64	76,2	5	5,9	8,5	N1XE-U5x10	-	-
400	KS4	H17	XS	20	30,9	5	5,9	8,5	N1XE-U5x10	-	N1XE-U5x16
400	KS4	H18	XS	26	37,1	5	5,9	8,5	N1XE-U5x10	-	N1XE-U5x16
400	T2	H19	L	16,5	27,3	100	117,6	169,8	N1XE-A4x150	-	-
400	T1	H2	M	70	82,4	50	58,8	84,9	N1XE-A4x95	-	-
400	T2	H20	S	52,5	64,4	20	23,5	34	N1XE-A4x50	-	-
400	KS5	H21	XS	99	112,3	5	5,9	8,5	N1XE-U5x10	-	-
400	KS5	H22	XS	72	84,5	5	5,9	8,5	N1XE-U5x10	-	-
400	KS5	H23	XS	55	67	5	5,9	8,5	N1XE-U5x10	-	-
400	KS5	H24	XS	36,5	47,9	5	5,9	8,5	N1XE-U5x10	-	-
400	KS1	KS2	-	72	84,5	15	17,6	25,5	N1XE-A4x50	-	-
400	KS5	H25	XS	11,5	22,1	5	5,9	8,5	N1XE-U5x10	-	-
400	KS5	H26	XS	96	109,2	5	5,9	8,5	N1XE-U5x10	-	-
400	KS5	H27	XS	42	53,6	5	5,9	8,5	N1XE-U5x10	-	-
400	KS5	H28	XS	37	48,4	5	5,9	8,5	N1XE-U5x10	-	-
400	KS5	H29	XS	26	37,1	5	5,9	8,5	N1XE-U5x10	-	-
400	T1	H3	M	41	52,5	50	58,8	84,9	N1XE-A4x95	-	-
400	KS5	H30	XS	103	116,4	5	5,9	8,5	N1XE-U5x10	-	-
400	KS5	H31	XS	82,5	95,3	5	5,9	8,5	N1XE-U5x10	-	-
400	KS6	H32	XS	6,5	17	5	5,9	8,5	N1XE-U5x10	-	N1XE-U5x16
400	KS6	H33	XS	7	17,5	5	5,9	8,5	N1XE-U5x10	-	N1XE-U5x16
400	KS6	H34	XS	11,5	22,1	5	5,9	8,5	N1XE-U5x10	-	N1XE-U5x16
400	KS6	H35	XS	48	59,7	5	5,9	8,5	N1XE-U5x10	-	-
400	KS6	H36	XS	42	53,6	5	5,9	8,5	N1XE-U5x10	-	-
400	KS6	H37	XS	28	39,1	5	5,9	8,5	N1XE-U5x10	-	-
400	KS6	H38	XS	17	27,8	5	5,9	8,5	N1XE-U5x10	-	-
400	KS6	H39	XS	89	102	5	5,9	8,5	N1XE-U5x10	-	-
400	T1	H4	L	55	67	100	117,6	169,8	N1XE-A4x240	-	-
400	KS6	H40	XS	50	61,8	5	5,9	8,5	N1XE-U5x10	-	-
400	KS6	H41	XS	26	37,1	5	5,9	8,5	N1XE-U5x10	-	-
400	KS6	H42	XS	80,5	93,2	5	5,9	8,5	N1XE-U5x10	-	-
400	KS6	H43	XS	63,5	75,7	5	5,9	8,5	N1XE-U5x10	-	-
400	KS6	H44	XS	47	58,7	5	5,9	8,5	N1XE-U5x10	-	-
400	KS6	H45	XS	28	39,1	5	5,9	8,5	N1XE-U5x10	-	-
400	T2	H46	XS	33	44,3	5	5,9	8,5	N1XE-U5x10	-	N1XE-U5x16
400	T2	H47	XS	39,5	51	5	5,9	8,5	N1XE-U5x10	-	N1XE-U5x16
400	T2	H48	XS	55,5	67,5	5	5,9	8,5	N1XE-U5x10	-	N1XE-U5x16
400	T2	H49	XS	33,5	44,8	5	5,9	8,5	N1XE-U5x10	-	N1XE-U5x16
400	T1	H5	L	52	63,9	100	117,6	169,8	N1XE-A4x240	-	-
400	KS7	H50	XS	45,5	57,2	5	5,9	8,5	N1XE-U5x10	-	-
400	KS7	H51	XS	34	45,3	5	5,9	8,5	N1XE-U5x10	-	-
400	KS7	H52	XS	38	49,4	5	5,9	8,5	N1XE-U5x10	-	-
400	KS7	H53	XS	10,5	21,1	5	5,9	8,5	N1XE-U5x10	-	-
400	KS8	H54	XS	43,5	55,1	5	5,9	8,5	N1XE-U5x10	-	-
400	KS8	H55	XS	29,5	40,7	5	5,9	8,5	N1XE-U5x10	-	-
400	KS8	H56	XS	38,5	50	5	5,9	8,5	N1XE-U5x10	-	-
400	KS8	H57	XS	28	39,1	5	5,9	8,5	N1XE-U5x10	-	-
400	T2	H58	XS	15	25,8	5	5,9	8,5	N1XE-U5x10	-	-
400	T1	H6	XS	50	61,8	50	58,8	84,9	N1XE-A4x95	-	-
400	T1	H7	L	111	124,6	100	117,6	169,8	N1XE-A4x240	-	-
400	KS1	H8	XS	33	44,3	5	5,9	8,5	N1XE-U5x10	-	-
400	KS1	H9	XS	15	25,8	5	5,9	8,5	N1XE-U5x10	-	-

Figure C.2: Cable calculations of Swedish Large grid

C.3 Cable calculations Venezuelan Mini grid

Voltage	From	To	Type	Length [m]	Real length [+10 m+3%]	[kW]	[kVA]	Current [A]	Current 125%	AWG (I-calc)	AWG (V-drop)	AWG (Ip-calc)
10000	PV	FS	-	257	275	300	352,9	20,4	26	10kV - 2	-	-
10000	Hydro	FS	-	192	208,1	114,209844	134,4	7,8	10	10kV - 2	-	-
10000	FS	T1	-	128	142,1	153,59386	180,7	10,4	13	10kV - 2	-	-
10000	FS	T2	-	134	148,3	260,615984	306,6	17,7	22	10kV - 2	-	-
240	T1	H1	M	83	95,8	10,15369	11,9	28,7	36	10	-	-
240	KS1	H10	S	17,5	28,3	6,236168	7,3	17,6	22	14	-	-
240	KS2	H11	S	31	42,2	6,236168	7,3	17,6	22	14	2	-
240	KS2	H12	S	62	74,2	6,236168	7,3	17,6	22	14	-	-
240	KS2	H13	S	17,5	28,3	6,236168	7,3	17,6	22	14	-	-
240	KS3	H14	S	30	41,2	6,236168	7,3	17,6	22	14	10	-
240	KS3	H15	M	62	74,2	10,15369	11,9	28,7	36	10	6	-
240	T1	KS1	-	155	170	37,417008	44	105,9	132	2	1/0	-
240	T1	KS3	-	77	89,6	16,369858	19,3	46,4	58	6	6	-
240	T1	KS4	-	73	85,5	18,708504	22	52,9	66	6	1/0	-
240	T2	KS5	-	139	153,5	68,597848	80,7	194,1	243	2/0	500	-
240	T2	KS6	-	163	178,2	87,306352	102,7	247,1	309	500	-	-
240	T2	KS7	-	87,5	100,4	24,944672	29,3	70,6	88	6	2	-
240	T2	KS8	-	106	119,5	24,944672	29,3	70,6	88	6	2	-
240	KS4	H16	S	64	76,2	6,236168	7,3	17,6	22	14	10	-
240	KS4	H17	S	20	30,9	6,236168	7,3	17,6	22	14	-	-
240	KS4	H18	S	26	37,1	6,236168	7,3	17,6	22	14	10	-
240	T2	H19	L	16,5	27,3	13,48791	15,9	38,2	48	10	6	-
240	T1	H2	M	70	82,4	10,15369	11,9	28,7	36	10	-	-
240	T2	H20	M	52,5	64,4	10,15369	11,9	28,7	36	10	6	-
240	KS5	H21	S	99	112,3	6,236168	7,3	17,6	22	14	2	-
240	KS5	H22	S	72	84,5	6,236168	7,3	17,6	22	14	-	-
240	KS5	H23	S	55	67	6,236168	7,3	17,6	22	14	2	-
240	KS5	H24	S	36,5	47,9	6,236168	7,3	17,6	22	14	-	-
240	KS1	KS2	-	72	84,5	18,708504	22	52,9	66	6	1/0	-
240	KS5	H25	S	11,5	22,1	6,236168	7,3	17,6	22	14	-	-
240	KS5	H26	S	96	109,2	6,236168	7,3	17,6	22	14	-	-
240	KS5	H27	S	42	53,6	6,236168	7,3	17,6	22	14	2	-
240	KS5	H28	S	37	48,4	6,236168	7,3	17,6	22	14	-	-
240	KS5	H29	S	26	37,1	6,236168	7,3	17,6	22	14	-	-
240	T1	H3	M	41	52,5	10,15369	11,9	28,7	36	10	10	-
240	KS5	H30	S	103	116,4	6,236168	7,3	17,6	22	14	2	-
240	KS5	H31	S	82,5	95,3	6,236168	7,3	17,6	22	14	-	-
240	KS6	H32	S	6,5	17	6,236168	7,3	17,6	22	14	6	-
240	KS6	H33	S	7	17,5	6,236168	7,3	17,6	22	14	-	-
240	KS6	H34	S	11,5	22,1	6,236168	7,3	17,6	22	14	-	-
240	KS6	H35	S	48	59,7	6,236168	7,3	17,6	22	14	6	-
240	KS6	H36	S	42	53,6	6,236168	7,3	17,6	22	14	-	-
240	KS6	H37	S	28	39,1	6,236168	7,3	17,6	22	14	-	-
240	KS6	H38	S	17	27,8	6,236168	7,3	17,6	22	14	2	-
240	KS6	H39	S	89	102	6,236168	7,3	17,6	22	14	-	-
240	T1	H4	L	55	67	13,48791	15,9	38,2	48	6	-	-
240	KS6	H40	S	50	61,8	6,236168	7,3	17,6	22	14	-	-
240	KS6	H41	S	26	37,1	6,236168	7,3	17,6	22	14	-	-
240	KS6	H42	S	80,5	93,2	6,236168	7,3	17,6	22	14	6	-
240	KS6	H43	S	63,5	75,7	6,236168	7,3	17,6	22	14	-	-
240	KS6	H44	S	47	58,7	6,236168	7,3	17,6	22	14	-	-
240	KS6	H45	S	28	39,1	6,236168	7,3	17,6	22	14	-	-
240	T2	H46	S	33	44,3	6,236168	7,3	17,6	22	10	-	-
240	T2	H47	S	39,5	51	6,236168	7,3	17,6	22	10	-	-
240	T2	H48	S	55,5	67,5	6,236168	7,3	17,6	22	10	-	-
240	T2	H49	S	33,5	44,8	6,236168	7,3	17,6	22	10	-	-
240	T1	H5	L	52	63,9	13,48791	15,9	38,2	48	6	-	-
240	KS7	H50	S	45,5	57,2	6,236168	7,3	17,6	22	14	6	-
240	KS7	H51	S	34	45,3	6,236168	7,3	17,6	22	14	-	-
240	KS7	H52	S	38	49,4	6,236168	7,3	17,6	22	14	6	-
240	KS7	H53	S	10,5	21,1	6,236168	7,3	17,6	22	14	-	-
240	KS8	H54	S	43,5	55,1	6,236168	7,3	17,6	22	14	6	-
240	KS8	H55	S	29,5	40,7	6,236168	7,3	17,6	22	14	-	-
240	KS8	H56	S	38,5	50	6,236168	7,3	17,6	22	14	6	-
240	KS8	H57	S	28	39,1	6,236168	7,3	17,6	22	14	-	-
240	T2	H58	S	15	25,8	6,236168	7,3	17,6	22	10	-	-
240	T1	H6	M	50	61,8	10,15369	11,9	28,7	36	10	-	-
240	T1	H7	L	111	124,6	13,48791	15,9	38,2	48	6	-	-
240	KS1	H8	S	33	44,3	6,236168	7,3	17,6	22	14	6	-
240	KS1	H9	S	15	25,8	6,236168	7,3	17,6	22	14	-	-

Figure C.3: Cable calculations of Venezuelan Mini grid

C.4 Cable calculations Venezuelan Large grid

Voltage	From	To	Type	Length [m]	Real length [+10 m+3%]	[kW]	[kVA]	Current [A]	Current 125%	AWG (I-calc)	AWG (V-drop)	AWG (Ip-calc)
10000	PV	FS	-	257	275	300	352,9	20,4	26	10kV 2	10kV 2	-
10000	Hydro	FS	-	192	208,1	580	682,4	39,4	49	10kV 2	10kV 2	-
10000	FS	T1	-	128	142,1	570	670,6	38,7	48	10kV 2	10kV 2	-
10000	FS	T2	-	134	148,3	310	364,7	21,1	26	10kV 2	10kV 2	-
240	T1	H1	M	83	95,8	50	58,8	141,5	177	1/0	1/0	-
240	KS1	H10	XS	17,5	28,3	5	5,9	14,2	18	14	6	-
240	KS2	H11	XS	31	42,2	5	5,9	14,2	18	14	2	-
240	KS2	H12	XS	62	74,2	5	5,9	14,2	18	14	-	-
240	KS2	H13	XS	17,5	28,3	5	5,9	14,2	18	14	-	-
240	KS3	H14	XS	30	41,2	5	5,9	14,2	18	14	14	-
240	KS3	H15	S	62	74,2	20	23,5	56,6	71	6	2	-
240	T1	KS1	-	155	170	30	35,3	84,9	106	2	3/0	-
240	T1	KS3	-	77	89,6	25	29,4	70,8	89	6	2	-
240	T1	KS4	-	73	85,5	15	17,6	42,5	53	6	2	-
240	T2	KS5	-	139	153,5	55	64,7	155,7	195	1/0	500	-
240	T2	KS6	-	163	178,2	70	82,4	198,1	248	2/0	500	-
240	T2	KS7	-	87,5	100,4	20	23,5	56,6	71	6	2/0	-
240	T2	KS8	-	106	119,5	20	23,5	56,6	71	6	2/0	-
240	KS4	H16	XS	64	76,2	5	5,9	14,2	18	14	10	-
240	KS4	H17	XS	20	30,9	5	5,9	14,2	18	14	14	-
240	KS4	H18	XS	26	37,1	5	5,9	14,2	18	14	14	-
240	T2	H19	L	16,5	27,3	100	117,6	283	354	500	500	-
240	T1	H2	M	70	82,4	50	58,8	141,5	177	1/0	1/0	-
240	T2	H20	S	52,5	64,4	20	23,5	56,6	71	6	6	-
240	KS5	H21	XS	99	112,3	5	5,9	14,2	18	14	6	-
240	KS5	H22	XS	72	84,5	5	5,9	14,2	18	14	-	-
240	KS5	H23	XS	55	67	5	5,9	14,2	18	14	6	-
240	KS5	H24	XS	36,5	47,9	5	5,9	14,2	18	14	-	-
240	KS1	KS2	-	72	84,5	15	17,6	42,5	53	6	2	-
240	KS5	H25	XS	11,5	22,1	5	5,9	14,2	18	14	-	-
240	KS5	H26	XS	96	109,2	5	5,9	14,2	18	14	-	-
240	KS5	H27	XS	42	53,6	5	5,9	14,2	18	14	6	-
240	KS5	H28	XS	37	48,4	5	5,9	14,2	18	14	-	-
240	KS5	H29	XS	26	37,1	5	5,9	14,2	18	14	-	-
240	T1	H3	M	41	52,5	50	58,8	141,5	177	1/0	1/0	-
240	KS5	H30	XS	103	116,4	5	5,9	14,2	18	14	6	-
240	KS5	H31	XS	82,5	95,3	5	5,9	14,2	18	14	-	-
240	KS6	H32	XS	6,5	17	5	5,9	14,2	18	14	6	-
240	KS6	H33	XS	7	17,5	5	5,9	14,2	18	14	-	-
240	KS6	H34	XS	11,5	22,1	5	5,9	14,2	18	14	-	-
240	KS6	H35	XS	48	59,7	5	5,9	14,2	18	14	6	-
240	KS6	H36	XS	42	53,6	5	5,9	14,2	18	14	-	-
240	KS6	H37	XS	28	39,1	5	5,9	14,2	18	14	-	-
240	KS6	H38	XS	17	27,8	5	5,9	14,2	18	14	2	-
240	KS6	H39	XS	89	102	5	5,9	14,2	18	14	-	-
240	T1	H4	L	55	67	100	117,6	283	354	500	500	-
240	KS6	H40	XS	50	61,8	5	5,9	14,2	18	14	-	-
240	KS6	H41	XS	26	37,1	5	5,9	14,2	18	14	-	-
240	KS6	H42	XS	80,5	93,2	5	5,9	14,2	18	14	6	-
240	KS6	H43	XS	63,5	75,7	5	5,9	14,2	18	14	-	-
240	KS6	H44	XS	47	58,7	5	5,9	14,2	18	14	-	-
240	KS6	H45	XS	28	39,1	5	5,9	14,2	18	14	-	-
240	T2	H46	XS	33	44,3	5	5,9	14,2	18	10	10	-
240	T2	H47	XS	39,5	51	5	5,9	14,2	18	10	10	-
240	T2	H48	XS	55,5	67,5	5	5,9	14,2	18	10	10	-
240	T2	H49	XS	33,5	44,8	5	5,9	14,2	18	10	10	-
240	T1	H5	L	52	63,9	100	117,6	283	354	500	500	-
240	KS7	H50	XS	45,5	57,2	5	5,9	14,2	18	14	10	-
240	KS7	H51	XS	34	45,3	5	5,9	14,2	18	14	-	-
240	KS7	H52	XS	38	49,4	5	5,9	14,2	18	14	10	-
240	KS7	H53	XS	10,5	21,1	5	5,9	14,2	18	14	-	-
240	KS8	H54	XS	43,5	55,1	5	5,9	14,2	18	14	10	-
240	KS8	H55	XS	29,5	40,7	5	5,9	14,2	18	14	-	-
240	KS8	H56	XS	38,5	50	5	5,9	14,2	18	14	10	-
240	KS8	H57	XS	28	39,1	5	5,9	14,2	18	14	-	-
240	T2	H58	XS	15	25,8	5	5,9	14,2	18	14	14	-
240	T1	H6	XS	50	61,8	50	58,8	141,5	177	1/0	3/0	-
240	T1	H7	L	111	124,6	100	117,6	283	354	500	500	-
240	KS1	H8	XS	33	44,3	5	5,9	14,2	18	14	-	-
240	KS1	H9	XS	15	25,8	5	5,9	14,2	18	14	-	-

Figure C.4: Cable calculations of Venezuelan Large grid