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Impact Analysis of Remote-Controlled Disconnectors on Distribution System Reliability

A study regarding the effect of remote controlled dicsonnectors on interruption time

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Abstract

In this project, the interruption statistics of a substation located in Charlottenberg, Sweden was analyzed from various aspects to quantify the benefits of remote controlled disconnectors. Statistics were used from before and after the installation of the remote controlled disconnectors to investigate the reliability indices, such as SAIDI, SAIFI and CAIDI. Further investigation was conducted to identify where and how many remote controlled disconnectors are truly needed. The investigation was divided in two parts. The first part was based on current values from the existing network. The second part was based on theoretical calculation with average values calculated from historical events that occurred on the network. The results obtained, show that the remote controlled disconnectors have a large impact on the system interruption time, with approximately a minimum reduction of 30% and a maximum reduction of 60%. Furthermore, the results show that the location and quantity of the installed remote controlled disconnectors plays a crucial role to reduce the number of affected customers during an interruption. However, it was concluded that by placing large quantities of remote controlled disconnectors does not reduce the affected customers at a high rate. The reduction of SAIDI and the number of installed remote controlled disconnectors can be seen as an exponential function, where at some point reduction of SAIDI will subside. Moreover, external factors such as weather and geographical location of the network had an impact on the achieved results.

Keywords: Interruption time, Remote controlled disconnector, SAIDI, SAIFI, CAIDI

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Abbreviations

RCD	Remote Controlled Disconnector
BA	Break Area
SA	Sectionizing Area
CID	Customer Interruption Duration
SAIDI	System Average Interruption Duration Index
SAIFI	System Average Interruption Frequency Index
CAIDI	Customer Average Duration Index

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Introduction

1.1 Background

Ellevio is an electricity distribution company with more than 930 000 customers in Sweden and a cable network of 7 200 km. In recent years major investments have been made to increase the security of supply by replacing overhead lines with underground cables. An additional act has been to install RCDs in the 10-20 kV cable network that has not yet been rebuilt. The purpose of these devices is to quickly re-establish connections in the network and thus reduce the duration of interruptions. Installation of these RCDs has been carried out on overhead lines where historically there had been a problem with interruptions or it was determined that there is an increased risk of interference. Such interruptions are mostly caused by falling trees, animals and other factors.

1.2 Aim

The aim of this thesis is to investigate and demonstrate the effect and benefit of RCD, which contributes to decreasing downtime of the network. The main aspect to investigate will be on how the RCDs affected the value of reliability indices such as SAIDI and CAIDI before and after their installation. Additionally, if it is possible, make recommendations for how to determine in a cost-efficient way where and how many remote controlled disconnectors should be installed on an overhead line or in a whole system.

1.3 Limitations

The statistics will be investigated for Charlottenberg substation in Ellevio's distribution network. This thesis focuses on the effect of RCD on reliability indices such as SAIDI and CAIDI, other solutions which reduce the interruption duration are not considered.

2

Basics on Distribution System Reliability

2.1 Regulations on interruptions

2.1.1 Electricity Act

According to Electricity Act (1997: 857) chapter 3: Section 9 - Section 9a,"Obligation to transmit electrical power", a party holding a network concession is obliged to transfer electrical power under reasonable terms on behalf of another and the transmission of electrical power shall be of good quality. A network concessionaire shall ensure that interruption in the transmission of electricity to an electricity user never exceed 24 hours, but the law also deals with the electricity user's right to severance pay [1].

According to Electricity Act (1997: 857) Chapter 10: Section 9 - Section16, the concessionaire for the network to which the electricity user is directly connected shall pay compensation if the transfer of electricity is terminated for a continuous period of at least twelve hours. The electricity user is not entitled to compensation there as [1]:

"1 the outage results from the neglect of the electricity consumer,

2 the transmission of electrical power is discontinued so that measures can be taken that are justified for electrical power safety reasons or in order to maintain good operational and supply security and the outage does not last longer than the measures require,

3 the outage is attributable to a fault in a concessionaire's cable network and the fault results from an impediment outside the concessionaire's control that

the concessionaire could not reasonably have been expected to have anticipated and whose consequences the concessionaire could neither reasonably have avoided nor overcome, or

4 the outage is attributable to a fault in a cable network where the cables have a voltage of 220 kV or more. (SFS 2005:1110)"[1].

Compensation shall be paid by 12.5 per cent of the electricity user's annual network cost, in the event of a break between 12 and 24 hours. In case of interruptions longer than 24 hours, an additional fee is payable for each 24-hour period with 25 percent of the electricity user's annual network cost. However, during an interruption period, the compensation may not exceed 300 percent of the annual network cost [1].

2.1.2 Requirements from the Swedish Energy Market Inspectorate

The Energy Market Inspectorate (Energimarknadensinspektion,EI) is the organisation that controls the power distribution companies to comply with the regulations that exist. The reason for this is, electricity distribution is regarded as a natural monopoly and therefore requires regulation so that quality and price is reasonable [2].

The Energy Market Inspectorate takes into account the security of power supply in the pre-regulation of network tariffs in order to provide distributions companies with incentives to maintain and increase the security of supply. To obtain material for quality assessment, Energy Market Inspectorate requires annual reports of distribution statistics [2]. These statistics includes reliability indices, which are introduced later in this chapter.

2.1.3 Definition of interruption

In Sweden interruptions and interruption durations are defined in the Energy Market Inspectorate's regulations on interruption reporting, EIFS 2010: 5 Chap.2, Section § 1, and summarized underneath. According to the Swedish Energy Market Inspectorate's regulations, an interruption is defined as the state where a connection point is electrically disconnected in one or more phases from a powered network. For example, an interruption can be caused by switching failure in power grids or external events such as equipment failure, weather, falling trees, etc [3].

Interruptions are classified as announced interruption where the customers are notified before the power outage occurs and unannounced interruptions where no notification has been made. The announced interruption occurs because some sort of planned work needs to be made by the supplier of power. The unannounced interruption is divided into two parts, long interruption, and short interruption. The long interruption is classified as interruption longer than three minutes and the short interruption is between hundred milliseconds and three minutes [3].

An interruption's starting point is when the supplier of power is notified or should have been notified about the interruption. The ending point of an interruption is when the voltage has been restored to the specified operating voltage [3].

2.2 Reliability Indices

The definition of the reliability of a power distribution system is described as the ability to deliver uninterrupted power to customers. The reliability indices for distribution systems can be given in different forms and practices to explain the reliability of feeders, customers, and systems that supply power. There are normally two methods for evaluating the reliability of distribution systems, the first one is based on historical calculation and the second one is based on predictive calculation. The distribution grid is more affected by interruptions than the transmission grid, as the transmission grid is more protected against faults since it transfers a large amount of power. The transmission grid is protected for example by higher towers and paths that are cleared from trees [4].

The Swedish power network is divided into three different, transmission network (220-400 kV), regional network (40-130 kV) and local network (0,4- 20 kV). System interruptions are not common in the transmission network, but it may occur and when it does usually several hundred thousand of customers are affected. Significantly more common are interruptions in local networks which causes more outages for thousands of customers each year. Therefore, an attempt has been made calculate the reliability indices that includes, System Average Interruption Duration Index (SAIDI), System Average Interruption Frequency Index (SAIFI) and Customer Average Duration Index (CAIDI).[5]

2.2.1 SAIDI

SAIDI, which stands for System Average Interruption Duration Index is a measurement of the average interruption duration per customer and year. It's also measured in minutes or hours and can be calculated as follows [6]:

$$SAIDI = \frac{\text{Sum of customer interruption duration}}{\text{total number of customers served}} = \frac{\sum U_i N_i}{\sum N_i} \tag{2.1}$$

Where U_i is the annual interruption time and N_i is the number of customers at the load point i.

2.2.2 SAIFI

SAIFI, is the System Average Interruption Frequency Index and indicates the average number of interruptions that each individual customer would experience.[6]

$$SAIFI = \frac{\text{total number of customer interruptions}}{\text{total number of customers served}} = \frac{\sum \lambda_i N_i}{\sum N_i} \tag{2.2}$$

Where λ_i is the failure rate and the N_i is the number of customers at the load point i.

2.2.3 CAIDI

CAIDI, is the Customer Average Duration Index and it indicates the average interruption duration that a given customer would experience. Can also be calculated by dividing SAIDI with CAIDI.[6]

$$CAIDI = \frac{\text{sum of customer interruption duration}}{\text{total number of customer interruptions}} = \frac{\sum U_i N_i}{\sum \lambda_i N_i} = \frac{SAIDI}{SAIFI} \tag{2.3}$$

Where λ_i is the failure rate, U_i is the annual interruption time and the N_i is the number of customers at the load point i.

2.3 Reliability Improvements

2.3.1 Methods of reducing SAIDI

Reducing of SAIDI on overhead lines can be done through several different techniques. Largely, all techniques are divided into two groups. These two groups represent two different methods of improving SAIDI.

1. Reducing the frequency of failures
2. Reducing the number of affected customers and the interruption time

The first method reduces the rate of failures and the second one reduces the number of affected customers and the interruption time. These methods can be used separately or in combination.

Some examples of the first method are cabling, insulation of overhead lines and cleaning (cutting down trees around the overhead lines). While in the last option, in order to become fully secured from falling trees a field with a length of 40 meters has to be cleared, which is not practical. These methods reduce the frequency of failure. Using disconnectors and RCDs are examples of the second method. This method reduces the number of affected customers during a fault and reduces interruption time because the troubleshooting and sectionizing the fault area is achieved faster [7].

Disconnectors have traditionally been used to subdivide the line in case of unplanned and planned interruptions. In case of a fault, RCDs are most time-efficient to reduce the number of affected customers and the sectionizing time. However, it is more expensive [7].

2.3.2 General function of disconnector

A disconnector is a mechanical device that disconnects the line, usually during No-load condition. The main function of disconnectors is to provide safety for many reasons, for example, a visible disconnection and an isolating distance between two live parts for operational reasons or for maintenance and repair purposes. A disconnector is usually used in substations, but it is also used along transmission lines, for the reason of disconnecting the lines when a line fault occurs.[8]

2.3.3 Remote controlled disconnector

An RCD is a disconnector upgraded to be controlled remotely. The benefit of that is that can be controlled by connecting and disconnecting the line easily from a control room. RCDs are used to reduce the number of affected customers as well as to facilitate quick troubleshooting from the control room and further for the fitter. RCDs can reduce the SAIDI in interrupted areas through the ability that operators can quickly subdivide the line and sectionize the fault area. As a result, the number of affected customers will be reduced. The installation of RCD usually takes place in areas that have a high interruption.

There are different types of RCDs depending on where in the grid they are placed and their purpose of installation. With consideration to the purpose of this project, this thesis focuses on RCDs in the distribution grid which are used to break three-phase voltage circuit. RCDs are not considered equal to circuit breakers as they require an external action to be triggered. Additionally, they do not have the same specifications as disconnectors, as they can break or close the lines remotely. RCDs are usually controlled with radio waves or through the existing telecommunication network.

In case of an interruption, the routine for sectioning a fault with and without an RCD can be described as follows.

Without an RCD:

1. The circuit breaker operates and disconnects the whole line.
2. The troubleshooting starts and is conducted through communication between the control room and a field worker that must manually disconnect the line. The isolation of the fault can take several hours because the field worker has to drive to different locations with directions from the control room.

With an RCD:

1. The circuit breaker operates and disconnects the whole line.
2. The troubleshooting starts and can be conducted by the control room since they can operate the disconnectors remotely.
3. The fault area is discovered it will be remotely disconnected by an RCD.
4. The fault area will be manually isolated even further with the help of a disconnector, this action will be handled by a field worker.

3

Charlottenberg Distribution Station

3.1 Description of network

Charlottenberg is a small town in western Varmland, also located in the heart of Eda municipality. The municipality has 8500 inhabitants and is approximately six kilometers from the border with Norway.

The substation in Charlottenberg has fifteen lines that feed power to 2 882 customers across several neighboring municipalities. The substation has two transformers of 25 MVA that transforms down the voltage from 130 kV to 10 kV and distributes the power across all lines which have several distribution stations connected to them. Thereafter, each distribution station transforms down the voltage from 10 kV to 400 V and continues to distribute the power directly to consumers.[9]

3.2 Line L020-U

Line L020-U Häljeboda is a 10-kV line. The line is fed from the 020 Charlottenberg distribution station and has a total of 367 customers connected, and a total cable length of 48.9 km. This gives an average of about 133 meters of line per customer. There are 24 disconnectors that divide the line into 18 break areas (BA). The existing solution has 6 RCDs which create 5 section areas (SA). In addition, 88% of the line is insulated, which means that it consists of underground cable and overhead cable and the remaining are uninsulated lines. This indicates by the dashed and solid lines in the figure 3.1. The dashed line represents either an underground cable or over-head cable. The solid line represents an uninsulated line. Furthermore, by the available statistics, the most fault occurs in the area of the uninsulated line.

These areas are marked with red circles in the figure 3.1. An overview of the line and its distribution areas is shown in figure 3.1.

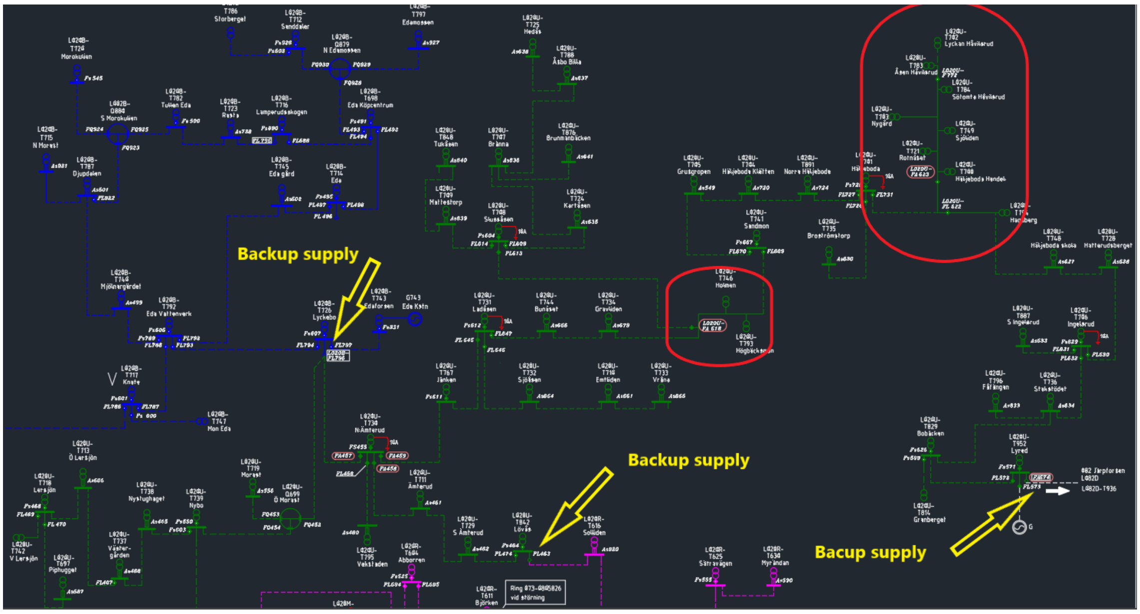

Figure 3.1: Line L020-U Häljeboda (The dark green line)

As shown in Figure 3.1, there are several backup feeders options for the Line L020-U. The yellow arrows in figure 3.1 indicate the places where there are opportunities for backup supply for the line. However, a backup feed of the line needs to be investigated from the load point of view because some of these backup feeders may have thinner conductors to feed the entire line. A backup feed is remotely maneuvered in the existing network and in the calculations, it is assumed that this backup feed can feed the entire line.

3.3 Line L020-E

Line L020-E Jarpforsen has some type of similarities with the line L020-U. The line is 10-kV and is fed from the same distribution station. It has a total of 283 customers, and a total of cable length of 46.8 km. This will give an approximate value of 165 meters of line per customer served. In addition, there are 15 disconnectors and 9 RCDs installed that divide the line into 16 BAs and 6 SAs. Furthermore, 95% of the line is insulated and an overview of the line is presented in figure 3.2.

As presented in Figure 3.2, there are several backup supply options for the Line L020-E. Although, the backup supply of the line needs to be examined from the load point of view since some of these backup feeders also may have weak conductors to feed most of the line. A backup supply is remotely maneuvered in the existing network and in the calculations, it is assumed that this backup supply can feed the entire line.

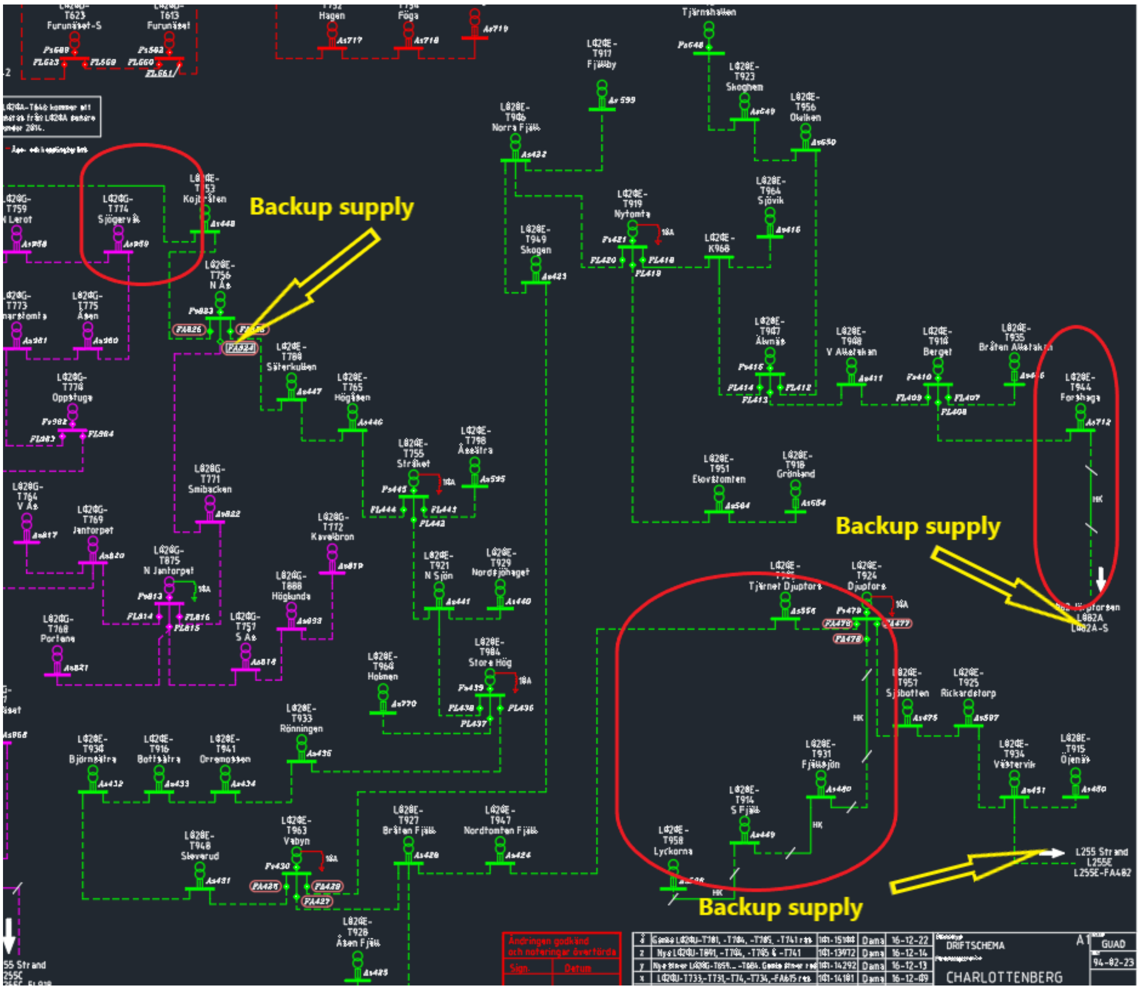

Figure 3.2: Line L020-E,(The light green line)

3.4 Line L020-G

Line L020-G Eda kyrka is a 10-kV line. The line is fed from the 020 Charlottenberg distribution station and has a total of 394 customers connected, and a total cable length of 46.3 km. This gives an average of about 117.5 meters of line per customer. There are 26 disconnectors that divide the line in 20 BAs. The existing solution has 7 RCDs which create 5 SAs. In addition, 81% of the line is insulated, which means it consists of cable and overhead cable and the remaining are uninsulated lines. Furthermore, by the available statistics, the most fault occurs in the area of the uninsulated line. An overview of the line and its distribution areas is shown in figure 3.3.

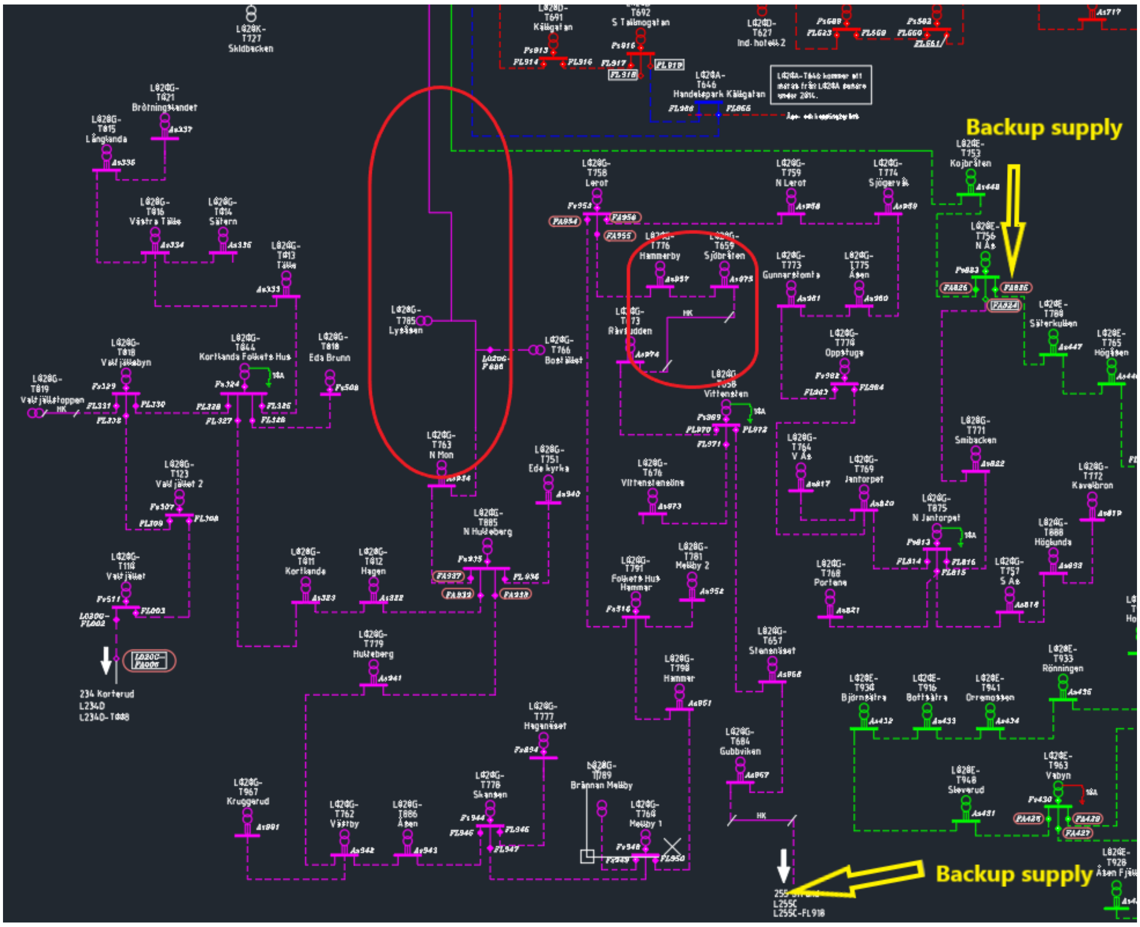

Figure 3.3: Line L020-G Eda kyrka (The purple line)

As shown in Figure 3.3, there are several backup feeder options for the Line L020-G. However, the backup feed of the line needs to be investigated from the load point of view because some of these backup feeds may have thinner conductors to feed the entire line. A backup feed is remotely maneuvered in the existing network and in the calculations, it is assumed that this backup feed can feed the entire line.

4

SAIDI and CAIDI before and after installation of RCD

To illustrate how the existing solution affects the customer interruption time and reliability indices in the lines, calculations are performed in lines L020-U, L020-E, and L020-G before and after installation of RCD's.

4.1 Before the installation of RCD

To calculate the customer interruption time and reliability indices before the installation of RCD's, the given data for interruptions statistics was filtered before the operating dates of RCD's. The operating dates of RCD's for line L020-U, L020-E, and L020-G are available in Table D.1. The time interval for calculation is set to one year before the operating dates. The time interval for line L020-U is set to 2010, for the line L020-E set to 2011 and for the line L020-G is set to 2010.

To calculate the SAIDI, the sum of all customer interruption time is calculated. Thereafter the value is divided by the total number of customers connected to the line. In order to calculate the CAIDI, the value of SAIFI was calculated first because CAIDI can be found by dividing the SAIDI by SAIFI. All results are summarized in Table 4.1.

Table 4.1: Statistics before installation of RCDs

Line	L020-U	L020-E	L020-G
Incidents [n/year]	3	16	8
SAIDI [h/year]	0.89	1.19	2.97
CAIDI [h/year]	1.03	1.07	0.56

4.2 After the installation of RCD

The calculation of reliability indices for after the installation of RCDs is made under the date MAY 2011 - APR 2012. That is due to the fact of the RCDs were taken into operation a couple of months before. For the sake of simplicity, these months are excluded from the calculation.

From previous sections, it was concluded that to calculate SAIDI the total number of customers must be known as well as the total customer interruption duration for that year. Almost the same values apply for calculating SAIFI, in this case, the failure rate is needed or the total number of interruptions that affect the group of customers. Lastly, calculating CAIDI is just dividing SAIDI by SAIFI as mentioned in subsection 2.2.3. The results are presented in Table 4.2.

Table 4.2: Statistics after installation of RCDs

Line	L020-U	L020-E	L020-G
Incidents [n/year]	1	2	4
SAIDI [h/year]	0.57	0.59	0.39
CAIDI [h/year]	0.56	0.21	0.22

4.3 Comparison

To compare the results from before and after installation of RCDs, figures 4.1 and 4.2 are used to demonstrate the total reduction of SAIDI and CAIDI in hours. For the line L020-U, SAIDI and CAIDI were reduced by 35% respectively 46%. For the line L020-E, SAIDI and CAIDI were reduced by 50% respectively 80%. Lastly, for the line L020-G, SAIDI and CAIDI were reduced by 87% respectively 67%.

Although, these values are excellent in terms of system reliability they are too high to be only caused by RCDs. During the last 3-5 years the insulation extent has been increased and at the same time large parts of the lines have been buried underground, see Table 5.1. This has led to the number of incidents/interruptions has decreased drastically.

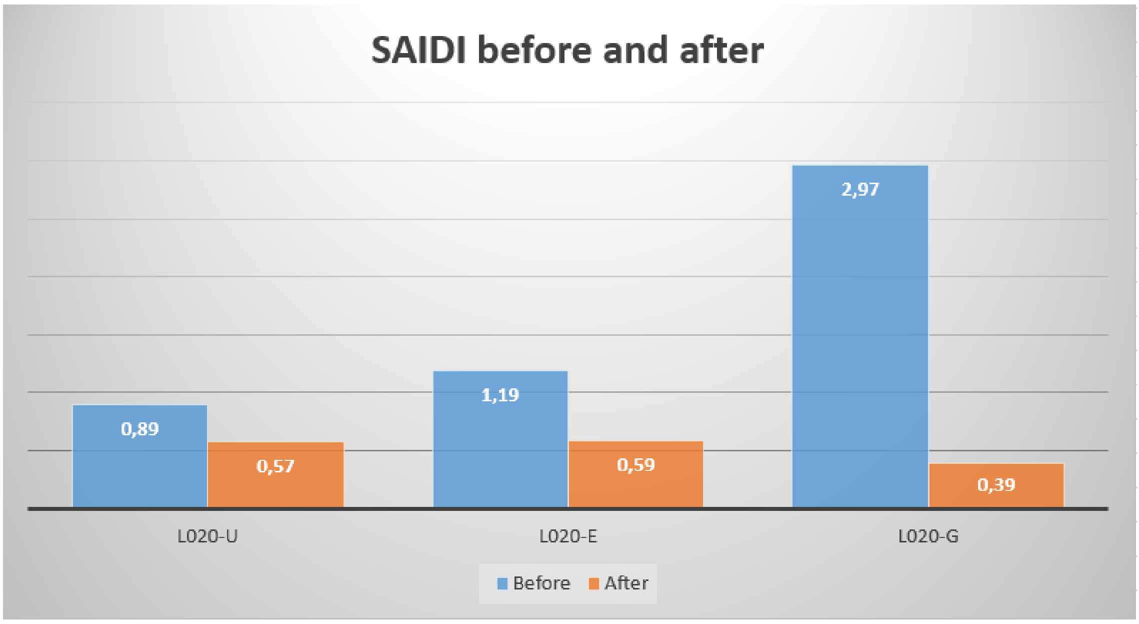

Figure 4.1: Values of SAIDI before and after installation of RCDs.

Note that to give a clear picture if the RCDs are worth the investments will be difficult. This is because the number of incidents has varied during the last couple of years. In order to see the effect of RCDs, the circumstances have to be the same before and after installation. Circumstances such as:

- Number of interruptions.
- Duration of each interruption should be the same in average.
- Number of affected customers in average.

Therefore, it has been decided that only the reliability indices should be studied.

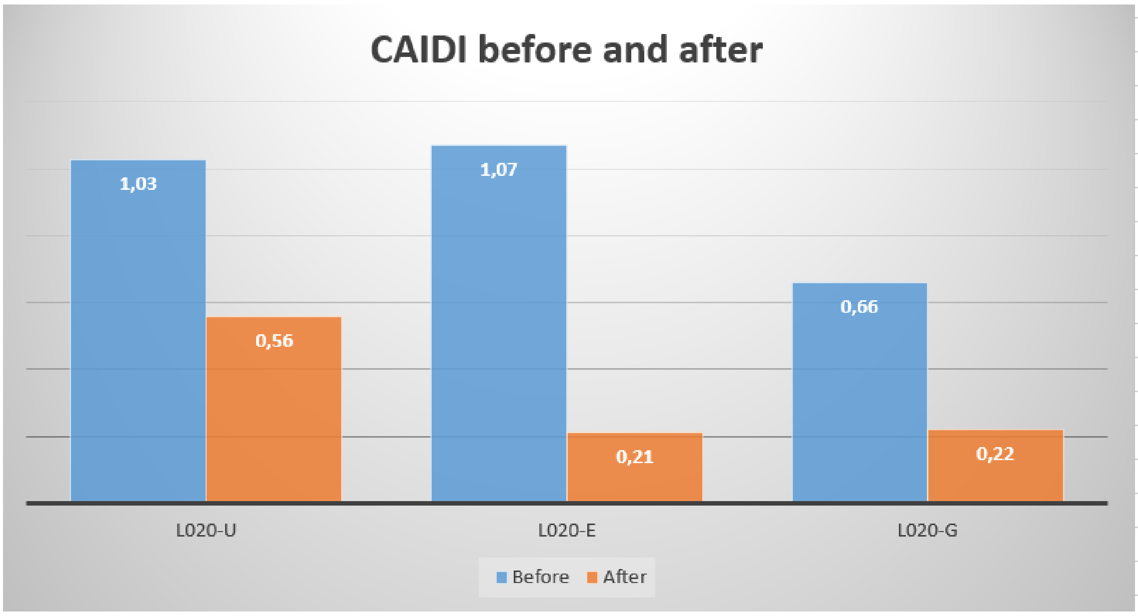

Figure 4.2: Values of CAIDI before and after installation of RCDs.

5

Theoretical investigation of RCD's effect on network

To illustrate and be able to investigate how the RCDs effect the customer interruption duration on a line and the reliability indices, a theoretical calculation has been performed. The aim of this theoretical calculation is an attempt to investigate how many RCDs should be installed per line. Moreover, wherein the line, RCD's should be placed for purpose of the best result.

5.1 Method and conditions for calculation

5.1.1 Conditions

To evaluate all three lines in the most accurate approach all lines will be evaluated with seven different alternative solutions. All seven solutions are presented in the result section of each line.

The calculation for this problem is based on one interruption at a time. The calculation of multiple numbers of interruptions at the same time is more complex and will not be considered in this thesis. Furthermore, it is also less likely to happen. Therefore, the interruption statistics for each line is collected from the given data from Xtenso and an average calculation has been made on each line. The average statistics are presented in section 5.1.2.1.

The break areas and the sectionized areas are given by the location of the disconnectors and RCDs in the existing solution of the line. The statistics for the lines length, number of customers served and type of line are also given form Xtenso.

As part of the conditions, the backup supply of power of the lines has been taken into consideration for the purpose of improving the use of the RCD. Additionally, it is assumed that switching points for backup supply is set up with RCDs.These RCDs have not been included in the number of RCDs in the different solutions, and further in the calculations.

As part of the calculation, sectioning with a circuit breaker or fuse of the network station is not taken into consideration. That is because the low voltage network is excluded from the calculation, as well as the types of faults and interruptions that occur in the 10/0.4 kV distribution substation. However, distribution substations that are equipped with disconnection capabilities are utilized to divide the network into more interruption areas. In this project, such stations are called ground distribution stations, which has the possibility of disconnecting the incoming line.

As part of the assumption, the majority of the disconnectors that exist on the three lines can be upgraded to remote controlled. Therefore, all existed disconnectors are assumed to have this feature.

The judgment when placing each RCD has been made upon the assumption of communication with the RCD is possible across all the lines. There are plenty of communication systems that can be used, an example of such system is GSM.

For each line evaluated, the data such as the number of customers served per interruption area and line lengths are presented in sections 5.2-5.4. Lastly, time factors and how an interruption in an interruption area can affect customers that are in separate locations have also been taken into account.

5.1.2 Method for calculation

5.1.2.1 Estimation of used data for Charlottenberg

In section five a historical approach was used to evaluate the effect of the RCDs installed. For the predictive approach, an estimation of values must be made based on historical events. Therefore, it was decided that an average calculation from historical events would give an approximate picture of future events.

The average calculation was conducted on the three different lines, L020-U, L020-E, and L020-G since their percentage of used over headlines are the highest, see Table 5.1. All calculation is based on a six-year average (2005-2010). The calculated average values for each line are presented in Table 5.2, Table 5.3 and Table 5.4. In the tables there are four rows, the number of incidents, affected customers, interruption duration, and the sum of all customer interruption duration. The data for these rows have been taken from the same excel sheets that have been used for previous calculation. For each row, an average value has been calculated by adding all the values from 2005-2010 and then divided by six. This gives an average value per year.

Table 5.1: Values of insulation extent for examined lines, values given in percent.

Line	**2013**	**2014**	**2015**	**2016**	**2017**
L020-E	70	85	95	95	95
L020-U	78	78	78	88	88
L020-G	76	76	76	76	81

Table 5.2: Statistics for line L020-E before installation of RCDs

Line L020-E	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**Average**
Number of incidents	19	7	17	10	7	6	11
Affected customers	2806	1468	2685	2336	1338	1376	2001.5
Interruption duration (h)	82.15	20.12	68.36	31.34	107.9	63.84	62.28
Customer interruption duration	4610	1576	4378	3985	2917	4565	3671.83

Table 5.3: Statistics for line L020-U before installation of RCDs.

Line L020-U	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**Average**
Number of incidents	8	2	11	20	14	3	10
Affected customers	1962	402	2673	4129	2861	108	2023
Interruption duration (h)	42.57	4.48	58.1	52.27	47.01	6.68	35.2
CID (h)	3246	722	3628	7365	3367	327	3109

Table 5.4: Statistics for line L020-G before installation of RCDs.

Line L020-G	2005	2006	2007	2008	2009	2010	Average
Number of incidents	8	8	9	5	0	1	5.16
Affected customers	1772	1690	1678	1607	0	43	1131.66
Interruption duration (h)	36.16	26.39	94.94	28.56	0	0.57	31.1
CID (h)	1171	3315	2611	7660	0	11	2461.33

5.1.2.2 Different solution

To evaluate all three lines in the most accurate approach that considers the circumstances, all lines will be evaluated with seven different alternative solutions. Every alternative means the line supplemented by a different quantity of RCDs. The quantity of RCDs is indicated by RDC-XX, where XX represents the number of RCDs. RCD-0 corresponds to an option without the possibility of remote sectioning which means there is no RCD used on the line. RCD-2 correspond to an option with two RCDs in the line etc. The last solution is where all disconnectors are replaced by RCDs.

5.1.2.3 Selection of line

As mentioned in previous chapters, RCDs can have a significant impact on reducing the customer interruption duration per incident and eventually reducing SAIDI. To have an understanding of how much of an impact there is, a calculation for three different lines with different circumstances has been made. Customer structure, cable type and the backup supply of power are the circumstances that have been focused on.

The selection of the three lines for calculation is based on the availability of the statics given by Xtenso, where the statistics will be investigated for one specific network area namely Charlottenberg distribution station. Furthermore, these three lines are the only lines in the distribution station that has RCDs connected to them. Additionally, the selected three lines provide the basis for calculation and conclusion, giving a wide variety of network lines. This gives a more accurate picture of the effect of RCDs on interruption time. These lines are L020-U, L020-E, and L020-G.

5.1.2.4 Fault location

The fault locations are decided based on historical events and statistics, where the most interruptions have been occurring. Equally important the fault locations is selected where there is an overhead line and at the same time spread the faults over the line to see the effects of RCDs in a more clear picture. The fault location selected somewhere in one break area.

5.1.2.5 Selection of break areas

The first step taken towards the goal of calculating SAIDI for each line is to break down the line into multiple Break Areas. To decide where a break area is located and how large it should depends on where a disconnector is installed and an action of disconnecting the line manually is needed.

5.1.2.6 Selection of RCD-locations

The location for each RCD is chosen with the intention of dividing a large group of customers into smaller groups. For the reason of when a fault occurs, fewer customers can be affected for extended periods of time. For each scenario, the number of customers is counted for that specific area and when that has been done, we target the large areas where most customers are located.

5.1.2.7 Calculation of customer interruption duration

To be able to calculate customer interruption duration, consideration must be taken that it takes different times to sectionize the fault location for repair. It is done in three different steps.

Figure 5.1: Steps of sectioning a fault.

t0: Fault occur, circuit breaker operates and disconnect the line
t1: The fault location sectionized by RCDs, circuit breaker operates and connect

the line
t2: The fault location further sectionized by manual disconnectors
t3: The Fault has been solved and all customers receive back the power

Every step of sectioning a fault takes different time. The time t1 is the time from when the interruption occurs to the time where the RCD has sectionized the interrupted area. It is defined as the "Interruption time before sectioning". This time is approximated to be ten minutes. It is the time that operator locate the fault location and a margin time, which is for safety reasons. In the operation room, you are supposed to wait a certain time before disconnecting the line. In the event of an accident and there are complications of getting in touch with operation room, it is useful to have a certain margin of time for such accidents. During this time the whole line is disconnected and consequently, all the customers are interrupted in ten minutes.

The time t2 is the time to sectionize the fault area furthermore manually by disconnectors. The duration of time t2 depends on where the fault location is and availability of staff and how fast they can reach the fault location. This time is set to roughly one hour in the calculations. During this time all the customers of the sectionized area are affected for an hour.

The time t3 is the interruption time, basically the reparation time, where the fault has been solved and all customers receive back the power. The duration of time t3 depends on the type and classification of fault. The reparation time can vary from seconds to days, the value is calculated by dividing the average interruption per year with the average number of incidents per year. The values needed are presented in subsection 5.1.2.1. For the line L020-U the reparation time is 3.52 [h], L020-E is 5.6 [h] and L020-G is 6.02 [h]. An average interruption duration for each line has been calculated in the previous section. This time is set to be the duration of time t3. During this time, only customers of the break area that the fault has been occurred at are interrupted.

5.2 Line L020-U

5.2.1 Selection of break areas

As seen in appendix A.1 L020-U has a total of eighteen BAs. Later when all BAs has been located, the number of distribution substation and the number of customers is counted, see Table D.2. The data is gathered from an excel file that has been received from Xtenso.

5.2.2 Fault location

The number of incidents/faults per year for the line L020-U has been calculated to ten in average, see table 6.2. For this reason, there will be a total of eleven faults divided across the line, each fault is located in a separate BA. As mentioned earlier, every fault location is chosen based on statistics where most interruptions have occurred and additionally where it is difficult to sectionize the fault. The chosen fault locations are presented in table A.1–A.7.

5.2.3 Calculation of customer interruption duration

The customer interruption duration is calculated in the way as discussed before under section 5.1.2.7. Under those circumstances, for each fault, the number of interrupted customers per sectionized area and break area is calculated. For the purpose of demonstration, an example is presented below for the calculation of the first fault (BA18), where the first parentheses represent the t1 and the second parentheses t2 and the last parentheses t3.

BA18) => (367*0.1667) + (150*1) + (19*3,52) = 278 [h]

Thereafter in the same fashion, the customer interruption duration for all faults has been calculated. In the end, all customer interruption duration summed up together and finally SAIDI is calculated by dividing the value by the total number of customers for the line. The result is summarized in tables A.1 - A.7.

To test the line furthermore how fast it can sectionize the interrupted area by using RCD's, the process continues in the same way. In every step, more and more disconnectors are replaced by RCD's in the same fashion mentioned earlier in the section 5.1.2.2. The result of calculations for all solutions are shown in table A.8.

5.3 Line L020-E

5.3.1 Selection of break areas

L020-E has a total of sixteen BAs which are presented in appendix.x. Similar for L020-E, when all BAs has been located, the number of distribution substation and the number of customers is counted, see Table D.2. The data is gathered from the same excel file that has been used for previous calculation.

5.3.2 Fault location

The number of incidents per year for the line L020-E has been calculated to eleven in average, see table 5.2. As a result, there will be a total of eleven faults divided across the line, each fault is located in a separate BA. Similar to the previous case of line L020-U, all faults are chosen based on statistics where most interruptions have occurred. The chosen fault locations are presented in table B.1 – B.7.

5.3.3 Calculation of customer interruption duration

The customer interruption duration is calculated in the way as discussed before under section 5.1.2.7. Under those circumstances, for each fault, the number of interrupted customers per sectionized area and break area is calculated.

Thereafter, the customer interruption duration for all faults is calculated see tables B.2 - B.7. In the end, all customer interruption duration summed up together and finally SAIDI is calculated by dividing the value by the total number of customers for the line. The result is presented in tables B.1 – B.7. The calculation continues for the remaining scenarios, all solutions are summarized in table B.8.

5.4 Line L020-G

5.4.1 Selection of break areas

The line L020-G has a total of 20 BA's (see appendix 5.1). Later when all BAs have been located, the number of distribution substation and the number of customers is counted, see Table D.2.

5.4.2 Fault location

The number of faults per year for the line L020-G has been calculated to six in average, see table 5.4. For this reason, there will be a total of six faults divided across the line, each fault is located in a separate BA. The chosen fault locations are in break area 2, 6, 10, 13, 19 and 20.

5.4.3 Calculation of customer interruption duration

The customer interruption duration is calculated in the same way as for line L020-U and L020-E. Thereafter in the same fashion, the customer interruption duration for all faults has been calculated see tables C.2 - C.7. In the end, all customer interruption duration summed up together and finally SAIDI is calculated by dividing the value by the total number of customers for the line.

To test the line furthermore how fast it can sectionize the interrupted area by using RCD's, the process continues in the same way. In every step, more and more disconnectors are replaced by RCD's in the same fashion mentioned earlier in the section 5.1.2.2. The result of calculations for all solutions are shown in tables C.8.

5.5 Comparison & Cost efficiency

To illustrate the results and improvements of the theoretical calculation in term of cost, a cost calculation has been performed. The aim of this cost calculation is to investigate and present how profitable it is to invest in different solutions. For the sake of simplicity, a rough economic estimation of what an RCD or upgraded disconnector to RCD costs is applied. In the cost calculation, a purchase price of approximately 100 000 kr has been used. The assumed value has been given by Xtenso. Table 5.5, 5.6, and 5.7 shows cost-effectiveness for the three investigated lines with the different solutions. From an economic perspective, it is more cost-efficient to invest in L020-E feeders first and then L020-U if the aim is to reduce the total system SAIDI. This can be seen more clearly in Table 5.8.

Table 5.5: Cost efficiency Line L020-U.

Solution	Cost [Mkr]	Reduced SAIDI [minute]	SEK/Reduced SAIDI [minute]
RCD-0	0	0	0
RCD-2	0.2	258	775
RCD-4	0.4	357	1120
RCD-6	0.6	377.4	1590
RCD-10	1	481.2	2078
RCD-15	1.5	493.8	3037
RCD-30	3	496.2	6046

Table 5.6: Cost efficiency Line L020-E.

Solution	Cost [Mkr]	Reduced SAIDI [minuet]	SEK/Reduced SAIDI [minute]
RCD-0	0	0	0
RCD-2	0.2	324	617
RCD-4	0.4	408	980
RCD-6	0.6	426	1408
RCD-10	1	504	1984
RCD-15	1.5	534	3809
RCD-24	2.4	536.4	4474

Table 5.7: Cost efficiency Line L020-G.

Solution	Cost [Mkr]	Reduced SAIDI [minute]	SEK/Reduced SAIDI [minute]
RCD-0	0	0	0
RCD-2	0.2	179.5	1114
RCD-4	0.4	223.2	1792
RCD-6	0.6	239.4	2506
RCD-10	1	271.2	3687
RCD-15	1.5	291.6	5144
RCD-33	3.3	299.4	11022

Table 5.8: Cost efficiency summary.

-		SEK/Reduced SAIDI [Minute]		
Solutions	Cost [Mkr]	L020-U	L020-E	L020-G
RCD-0	0	0	0	0
RCD-2	0.2	775	617	1114
RCD-4	0.4	1120	980	1792
RCD-6	0.6	1590	1408	2506
RCD-10	1	2078	1984	3687
RCD-15	1.5	3037	3809	5144
RCD-30	3	6046	-	-
RCD-24	2.4	-	4474	-
RCD-33	3.3	-	-	11022

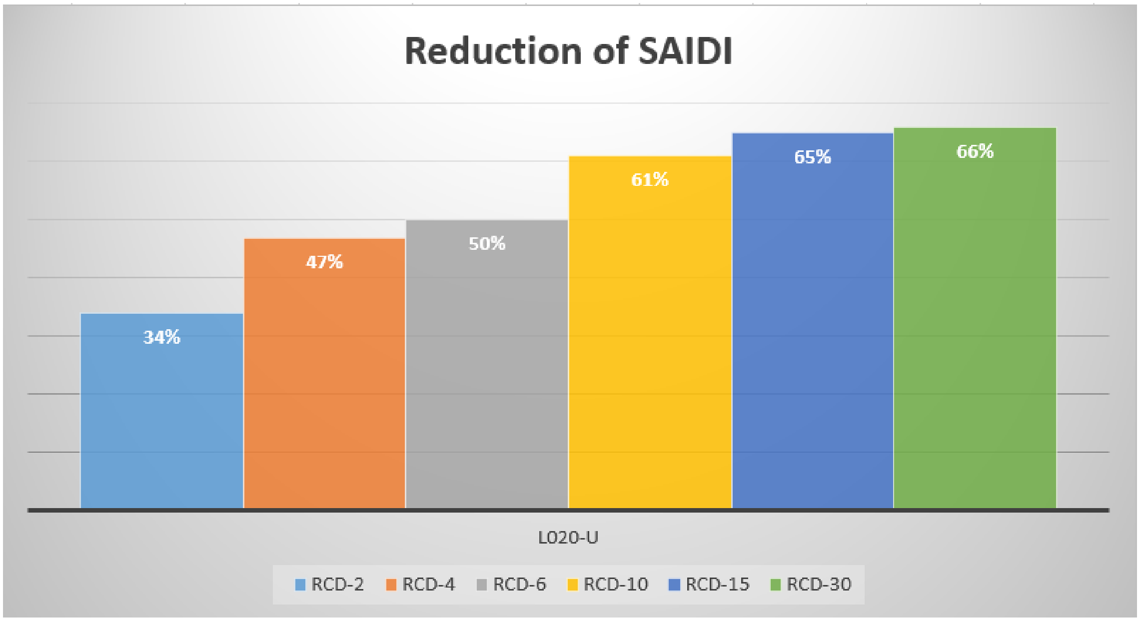

Figure 5.2: Reduction of SAIDI Line L020-U

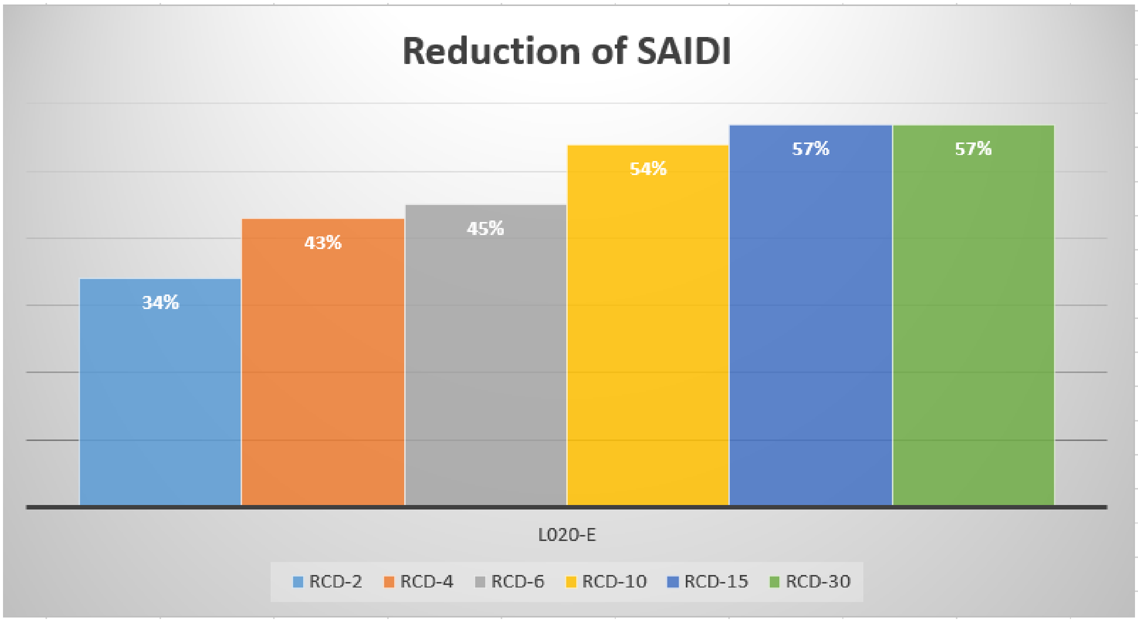

Figure 5.3: Reduction of SAIDI Line L020-E

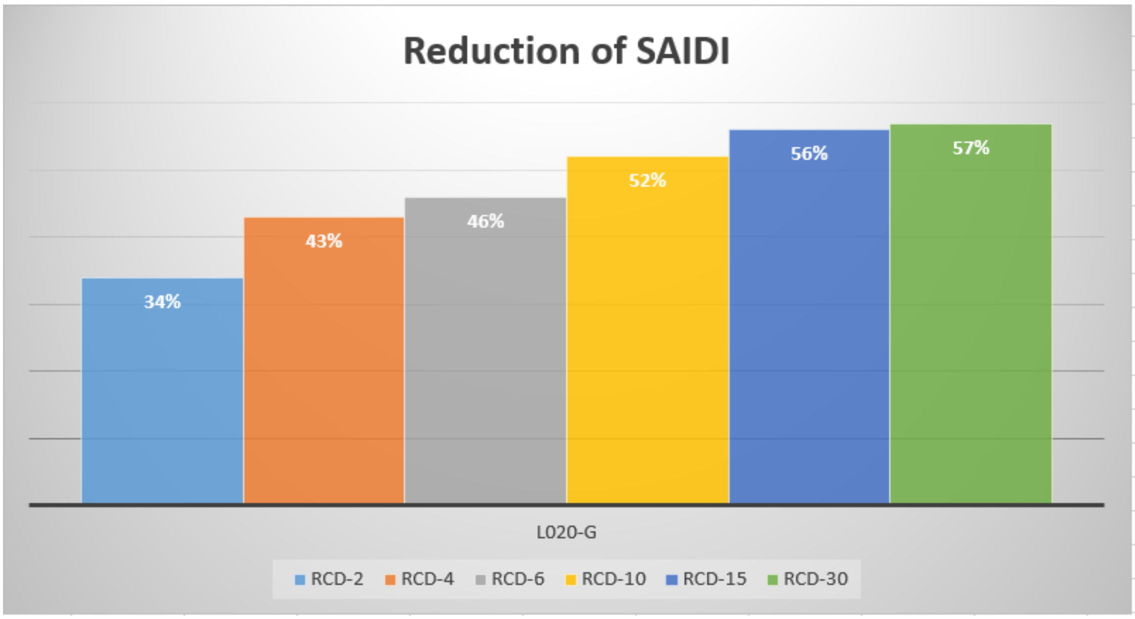

Figure 5.4: Reduction of SAIDI Line L020-G

A comparison between Tables 5.5, 5.6 and 5.7 and figures 5.2, 5.3 and 5.4 shows that reducing SAIDI minute for all three line occurs almost at the same rate. Despite the lines having different customer structure, a different number of customer, they follow a similar pattern. The more RCD in the line, the less SAIDI minutes have decreased, which made the first solution to the most cost-effective compared to the following solutions and the last solution to the least cost-effective solution.

The Tables 5.5, 5.6 and 5.7 also show the cost of reduced SAIDI per minute. The price per reduced SAIDI minute increases rapidly but on the other hand, reduced SAIDI minute increases sharply at the beginning and then continues very slowly. The Table 5.8 shows a summary of cost efficiency and a cost of reduced SAIDI per minute for all three lines.

An important point in cost efficiency when it comes to the reconstruction of the lines with RCDs is to consider that the cost of upgrading a disconnector to RCD and a new RCD is not the same. Since many RCDs in the solutions are placed where already a disconnector is installed. Therefore, cost-efficiency analysis alone should not be the basis for the installation of new RCDs. The Tables 5.5, 5.6 and 5.7 report prices for new RCDs.

6

Discussion and Conclusions

6.1 Analysis of the presented solutions

6.1.1 Location of RCDs

A strategic location for installation of RCD is the transition from cable to overhead line. This is because the faults on overhead lines are more likely to occur than cables.

In general, it affects SAIDI more to place RCDs on non-radial systems. Namely, in systems having remote-controlled backup supply, the fault area can be sectionized and the customer outside of the fault area can be quickly reconnected. In other words, it affects more on systems that have a meshed structure. Break area 14 in line L020-U confirming this because it can be clearly seen that SAIDI becomes more difficult to impact with RCD on this radial line between break area 14 and 15. It does not help to install RCD between break area 14 and 15 because the area 14 does not have backup supply and it is not possible to sectionize the area if a fault occurs in break area 15.

In single radial feeder systems, the customers furthest away does not get any benefit from the RCDs if they are placed at the beginning of the radial. The only benefit for those customers at the end of a radial is that troubleshooting can go faster. In this case, the reliability indices of load points near to the supply are improved, the amount of improvement is greater for those near to the supply point and less for those further from it. The indices of load point furthest away remain unchanged because isolation cannot remove the effect of any failure on this load point [6].

As mentioned earlier, it is a great advantage to use RCDs at switching points for backup supply to quickly feed the lines or parts of the lines in case of fault on the main feeder. Therefore, use of RCDs at these points is recommended. However, placement of RCDs at the switching points for backup supply is meaningless for the line if there is no further RCD along the line because it will only become one sectionized area.

As a general recommendation, switch points for backup supply should set up with RCDs and furthermore, lines should have at least one RCD located along the line. Then the line will be divided into more sectionized areas, which improves the customer interruption time for the line.

In systems where disconnectors are already operating in strategic locations, there is an economic advantage regarding expansion with RCDs. Those positions where disconnectors are installed can be upgraded with RCDs. In most cases, there is no need to calculate a cost for new RCD, as the existing one can be upgraded with the RCD.

By comparing the lines that need to be upgraded by RCDs with the investigated lines, approximate improvement potentials and costs can be obtained if the lines have a similar structure and interruption statistics.

6.1.2 Most cost effective solution

For all three lines, the key statistics that show customers per SA and number of customers per BA have varying sizes and therefore no direct connection could be found. This depends mainly on the number of factors that are involved, such as customer structure, type of line, number of interruptions, etc. For this reason, a general conclusion regarding how many RCDs that are needed to reduce SAIDI is difficult to achieve.

Notably, from table 5.8 the first two RCDs are much more cost effective than those that are installed afterward. Also, the cost-effectiveness in relation to the number of RCDs can be seen as an exponential function. See figure 6.1.

Furthermore, from Table 5.5 to 5.7 it can be decided which solution is the best for each line. For the lines L020-U and L020-G, the best solution is RCD-4 since they offer more value for the money. However, for line L020-E it is more complicated to draw a conclusion since both RCD-4 and RCD-10 offer decent amount of reduced SAIDI minutes. The difference between them is 96 minutes of reduced SAIDI, therefore it will come down to two factors. First one is how much money the substation owner is willing to invest and the second is how much SAIDI needs to be reduced.

How much SAIDI or the interruption time can be reduced using RCDs depends heavily on the possibility of backup-power supply. In cases where there is a possible backup-power supply, it is a smart decision to place an RCD at that location, then it can feed some part or the whole line when a fault occurs. Similarly, this could be helpful when there is a planned power outage.

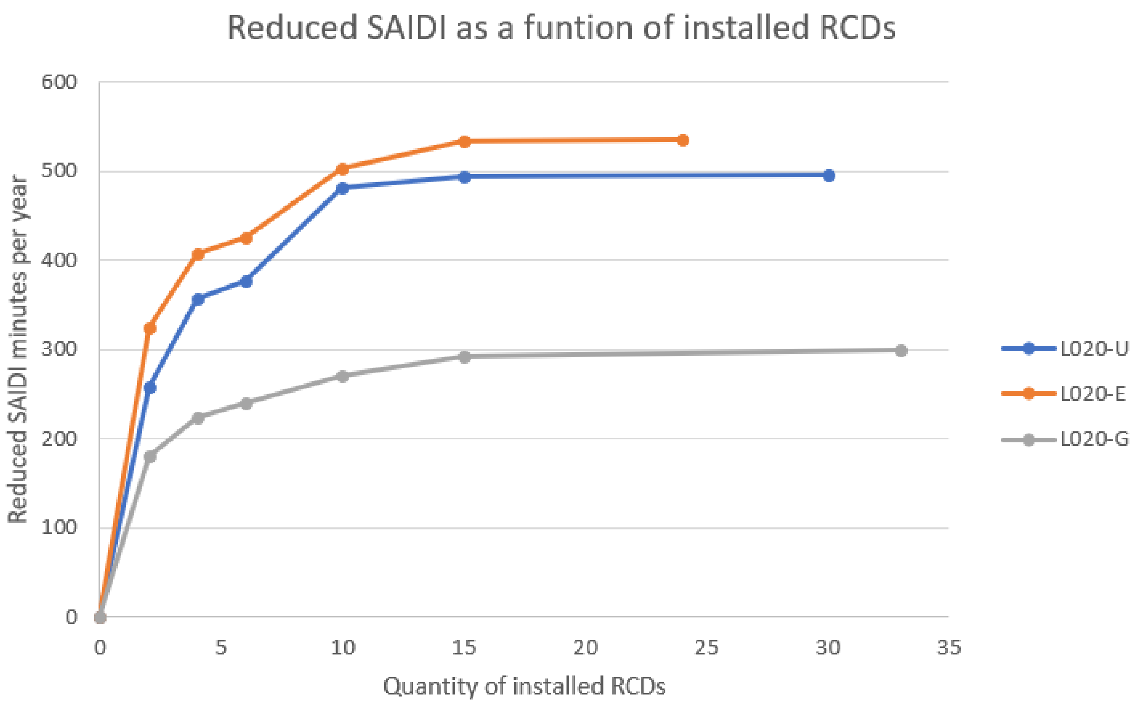

Figure 6.1: Exponential function that showcase the relation between reduced SAIDI and quantity of installed RCDs.

6.2 Conditions for using the presented solution

All the presented solutions are tailored for each specific line since the calculated average values are taken from historical events that have occurred on the line. Geographical location of each line has been taken into consideration since some part of the lines passes through multiple forests. The insulation extent and customer structure of each line made an impact on each presented solution.

Furthermore, implementing these solutions on other lines could lead to different results because of the topics mentioned above. The same method can still be used, however, a similar conclusion might not be the end result.

6.3 Recommendation for future work

6.3.1 Conditions on before and after calculation of SAIDI CAIDI

To simplify the calculation of SAIDI & CAIDI when examining a line or a distribution network, the circumstances must be the same both before and after. In this project, the circumstances did change since the installation of the RCDs, both the insulation extent of all lines became higher and at the same time changing weather played a significant role in the calculation. The number of interruptions and the interruption duration was reduced significantly. To have a more accurate result, the number of interruptions and the interruption duration should be the same on average. Moreover, a statistic that could be helpful is to identify is how many times each RCD has been operated during a specific period. This could be helpful by quickly identifying the areas that are more affected by interruptions.

6.3.2 Recommendation for the theoretical calculation

The theoretical calculation will be more accurate if each line is investigated with more solutions. It would give a better result if the number of RCD increased periodically and the steps between different solutions are not so large. At the same time, the average calculation could be justified to be more accurate, by calculating over longer periods of time. Moreover, taking the weather conditions such as storms and heavy weather into consideration and adjusting the average values could give a more accurate result.

By making fewer assumptions and use values that are based on facts or research, could change the end results significantly. For example the assumption of duration for t1 and t2 in the calculation of customer interruption duration. The results would have been more accurate and realistic if the values were based on accurate facts and statistics regarding the duration of t1 and t2, instead of 10 minutes and one hour.

For future work, the method implemented in this project could be automatized. However, it may not give a more accurate result, but it could reduce the time of the initial investigation. An automatized method could quickly give a value of SAIDI or CAIDI that helps the investigator with a an initial look.

6.3.3 Interruption cost estimate

As mentioned earlier the Energy Market Inspectorate (EI) is an authority responsible for overseeing the activities of network owners such as Ellevio AB and has a function as a link between the customer and the electricity supplier in order to achieve the best possible result.

EI states in Regulation FIFS 2015:5, valuation of Interruption costs for the different type of customers. EI presents a table for cost per kilowatt hour (SEK/kWh) for not supplied Energy and cost per kilowatt (SEK/KW) for non-delivered power for different customer types. See table 6.1.

By obtaining average non-delivered power during the interruption period and using the values in the table 6.1, a cost calculation for Interruption costs can be implemented. Thereafter, a cost analysis for finding the critical point for the investment of the RCD can be made.

Table 6.1: Interruption cost valuation

Price 2013	Unplanned interruption		Planned interruption	
	Cost per Energy SEK/kWh	Cost per Power SEK/kW	Cost per Energy SEK/kWh	Cost per Power SEK/kW
Industry	71	23	70	22
Trade and services	148	62	135	41
Agriculture	44	8	26	3
Public sector	39	5	24	4
Household	2	1	2	0
Boundary points	66	24	61	18

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A

L020-U

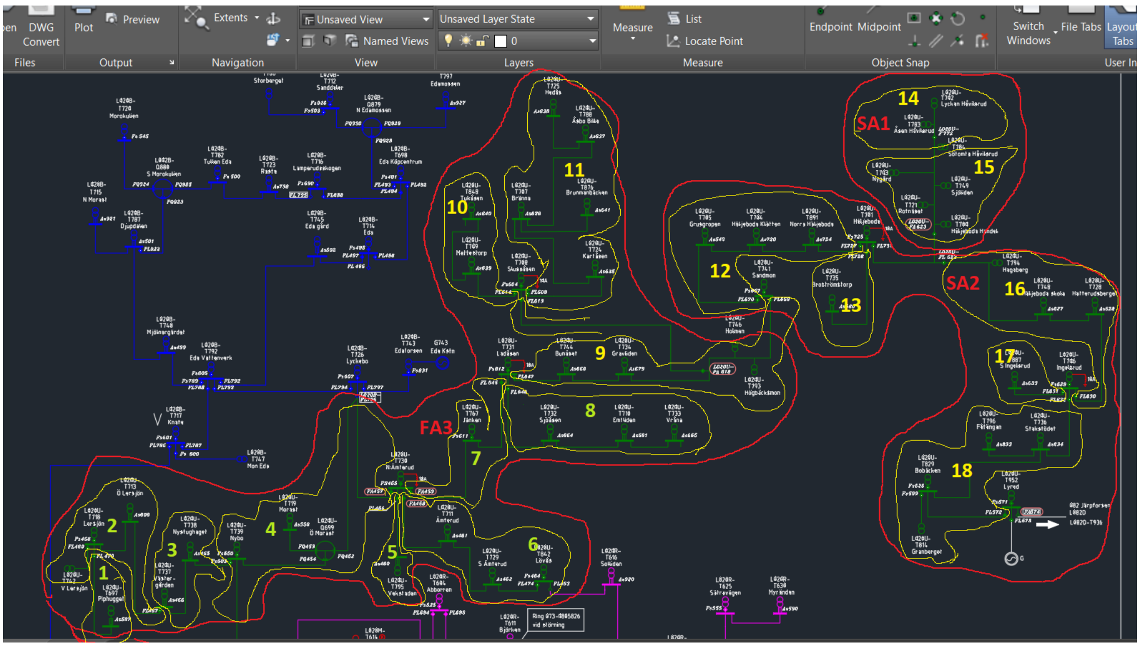

Figure A.1: Line L020-U, Scenario RCD-2

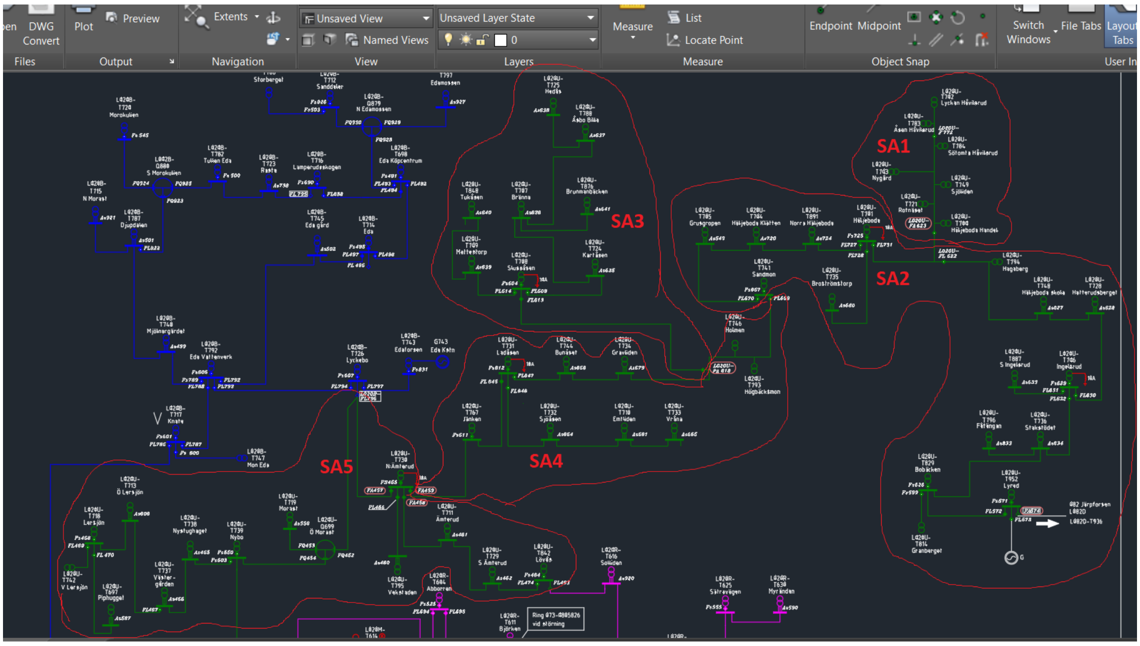

Figure A.2: Line L020-U, Scenario RCD-4

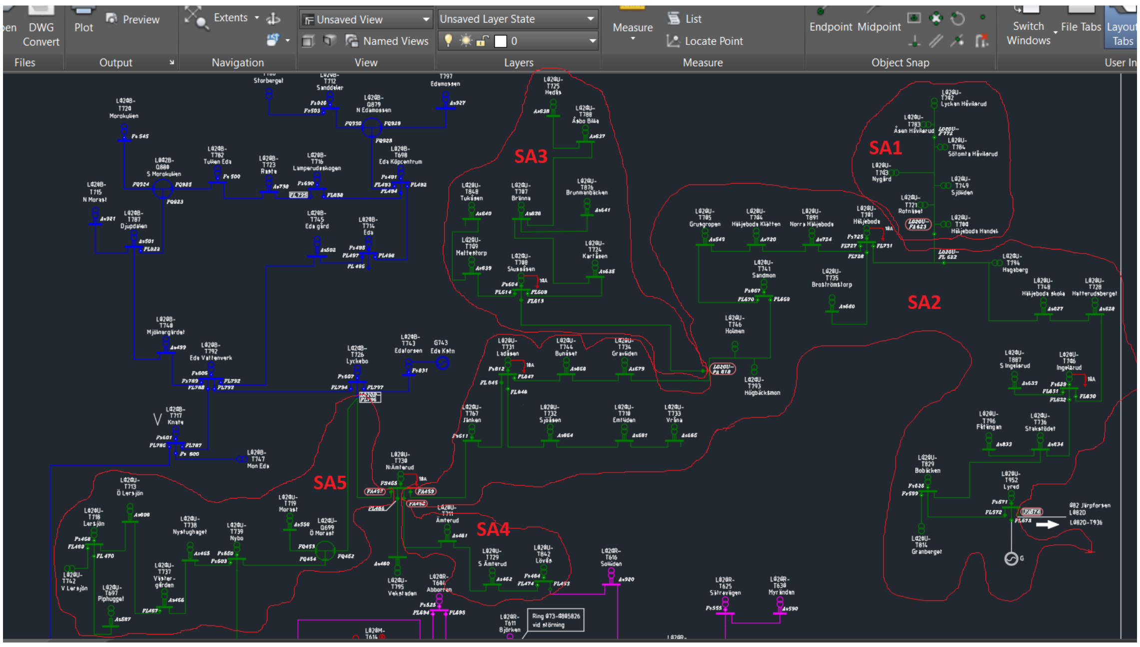

Figure A.3: Line L020-U, Scenario RCD-6

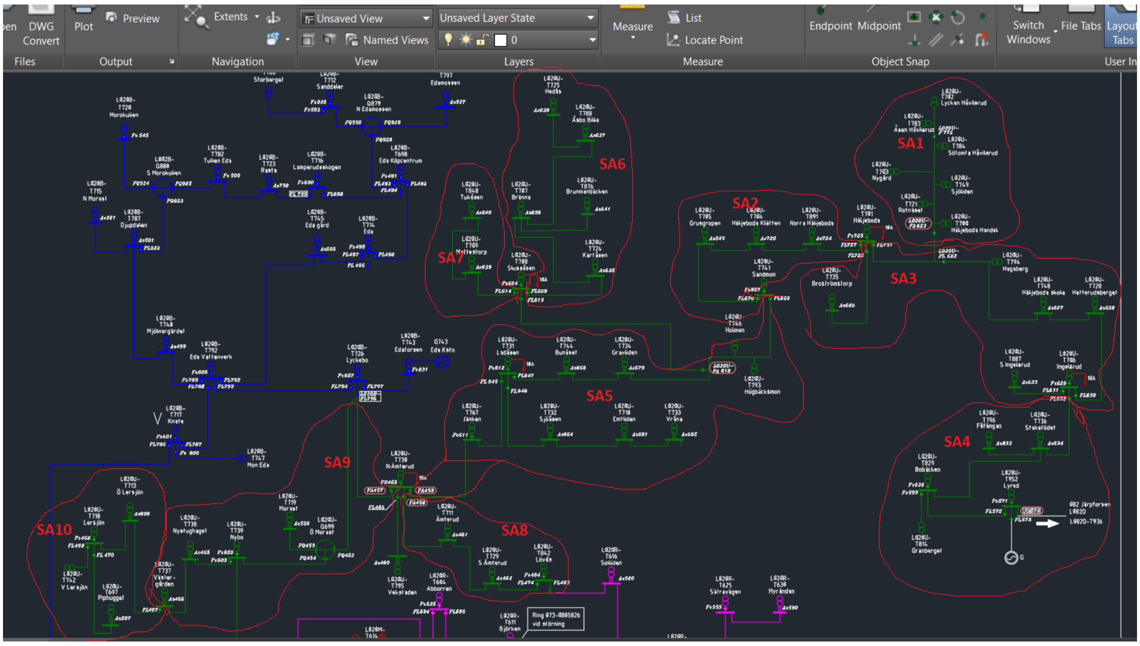

Figure A.4: Line L020-U, Scenario RCD-10

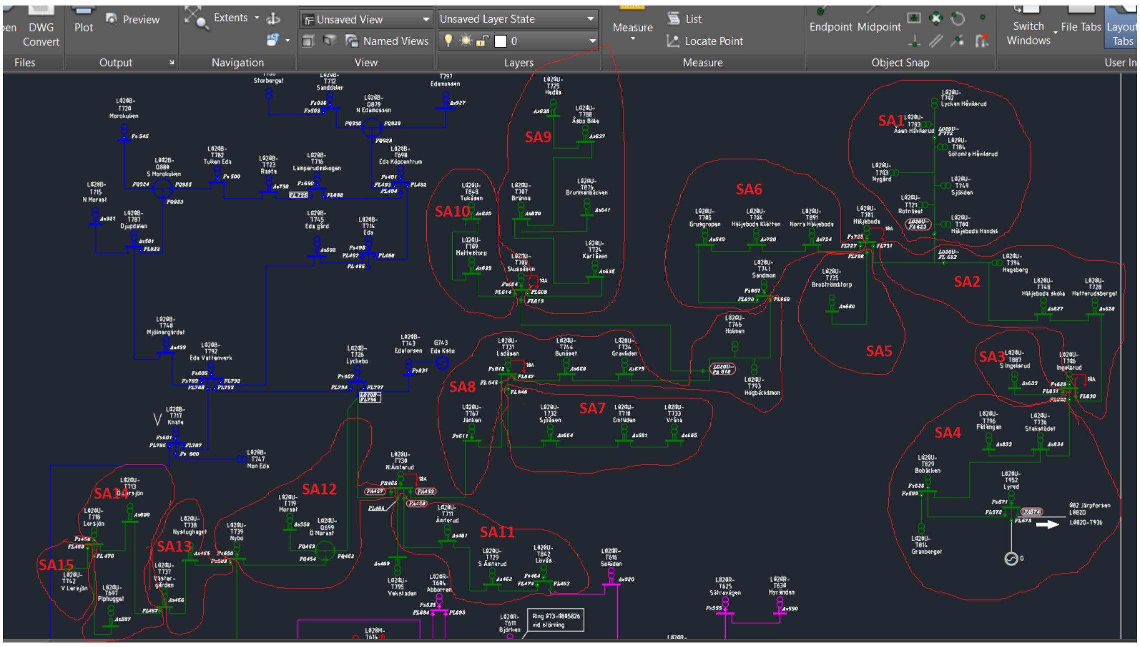

Figure A.5: Line L020-U, Scenario RCD-15

Table A.1: Line L020-U, Scenario RCD-0.

Break Area	Sum of all customer interruption duration (h)
BA18	434
BA16	448
BA15	617
BA12	448
BA11	437
BA9	402
BA8	423.3
BA6	462
BA4	494
BA2	483

Table A.2: Line L020-U, Scenario RCD-2.

Break Area	Sum of all customer interruption duration (h)
BA18	278
BA16	292.1
BA15	311.1
BA12	221.1
BA11	316.6
BA9	281.4
BA8	302.5
BA6	341.2
BA4	372.9
BA2	358.8

Table A.3: Line L020-U, Scenario RCD-4.

Break Area	**Sum of all customer interruption duration (h)**
BA18	278
BA16	292.1
BA15	311.1
BA12	221.1
BA11	154.16
BA9	127.36
BA8	148.48
BA6	287.2
BA4	318.9
BA2	304.8

Table A.4: Line L020-U, Scenario RCD-6.

Break Area	Sum of all customer interruption duration (h)
BA18	278
BA16	292.1
BA15	311.1
BA12	292.1
BA11	154.6
BA9	127.4
BA8	148.5
BA6	156.2
BA4	284.9
BA2	270.8

Table A.5: Line L020-U, Scenario RCD-10.

Break Area	**Sum of all customer interruption duration (h)**
BA18	128
BA16	175.1
BA15	311.1
BA12	142.12
BA11	131.6
BA9	127.4
BA8	148.5
BA6	156.2
BA4	251.9
BA2	206.9

Table A.6: Line L020-U, Scenario RCD-15.

Break Area	Sum of all customer interruption duration (h)
BA18	128
BA16	142.12
BA15	311
BA12	142.12
BA11	131.6
BA9	111.4
BA8	117.5
BA6	156.2
BA4	187.9
BA2	177.3

Table A.7: Line L020-U, Scenario RCD-30.

Break Area	**Sum of all customer interruption duration (h)**
BA18	128
BA16	142
BA15	311
BA12	142.12
BA11	131.6
BA9	96.4
BA8	117.5
BA6	156.2
BA4	187.9
BA2	177

Table A.8: Line L020-U, summary of results.

Scenario	CID	SAIDI [h]	Improvements compared to the previous solution, %	Improvements compared to zero installed RCDs, %
RCD-0	4648.3	12.6	-	-
RCD-2	3075.8	8.3	-34	-34
RCD-4	2443.6	6.65	-20	-47
RCD-6	2315.7	6.31	-5	-50
RCD-10	1778.72	4.85	-23	-61
RCD-15	1605.06	4.37	-9.9	-65
RCD-30	1589.76	4.33	-1	-66

B

L020-E

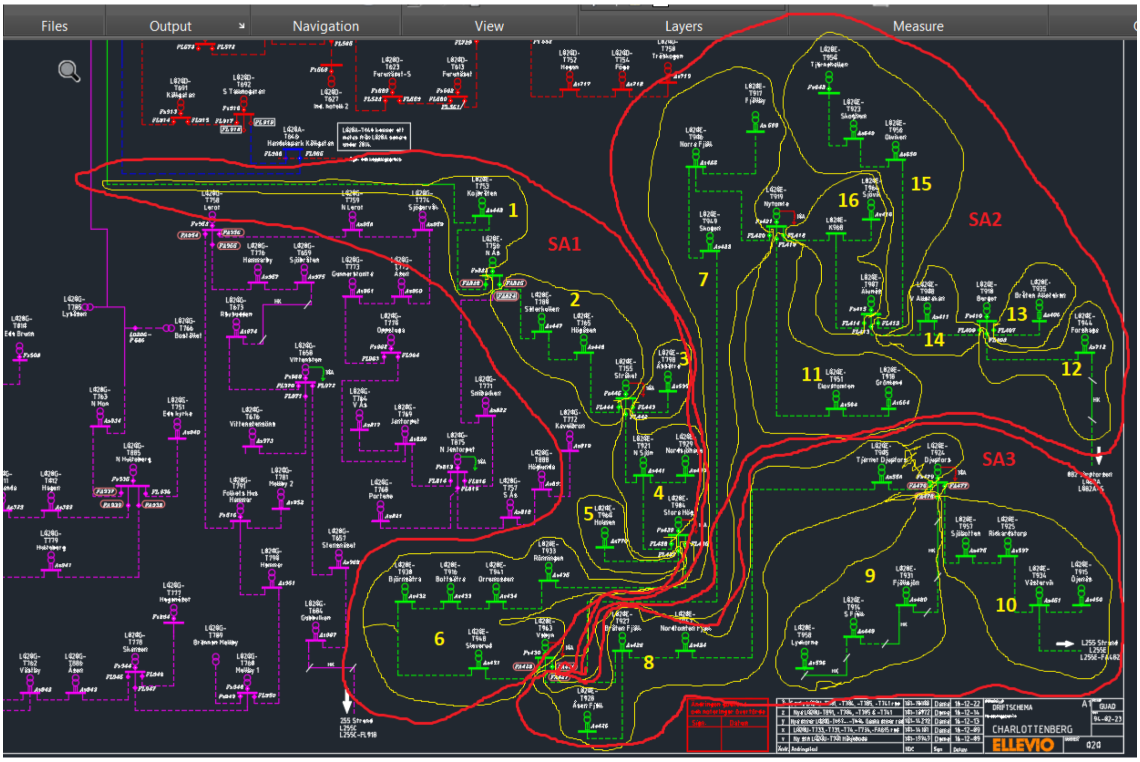

Figure B.1: Line L020-E, Scenario RCD-2

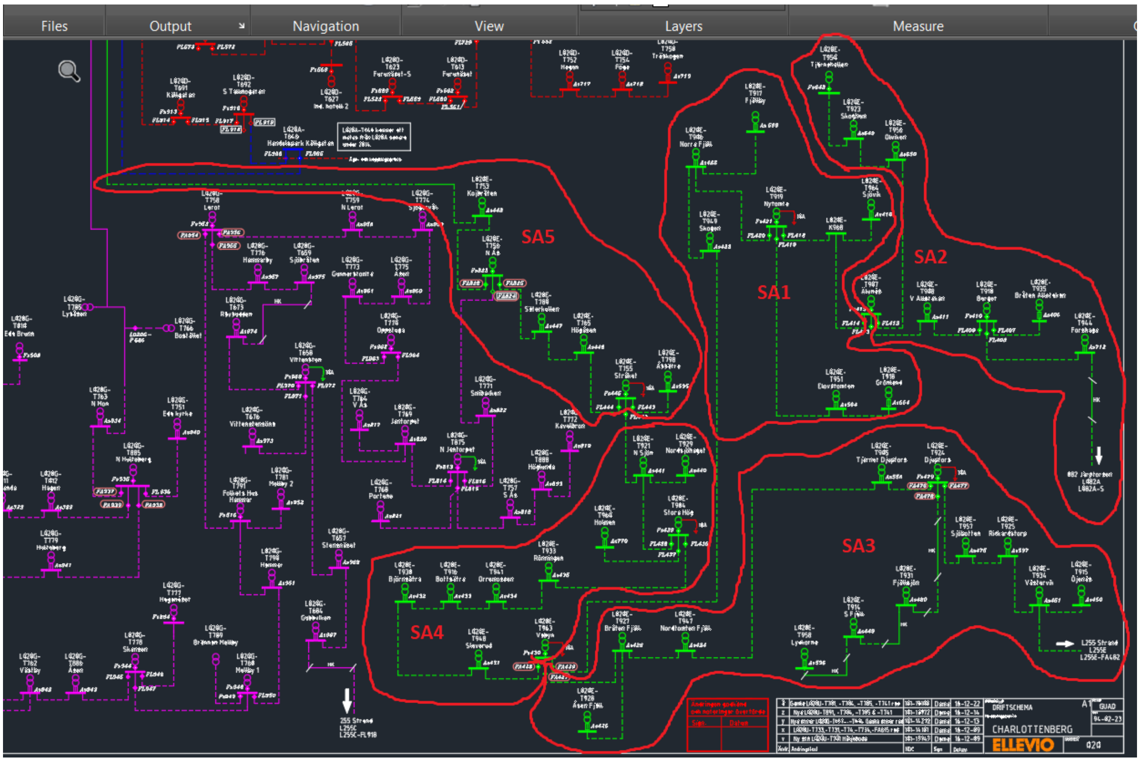

Figure B.2: Line L020-E, Scenario RCD-4

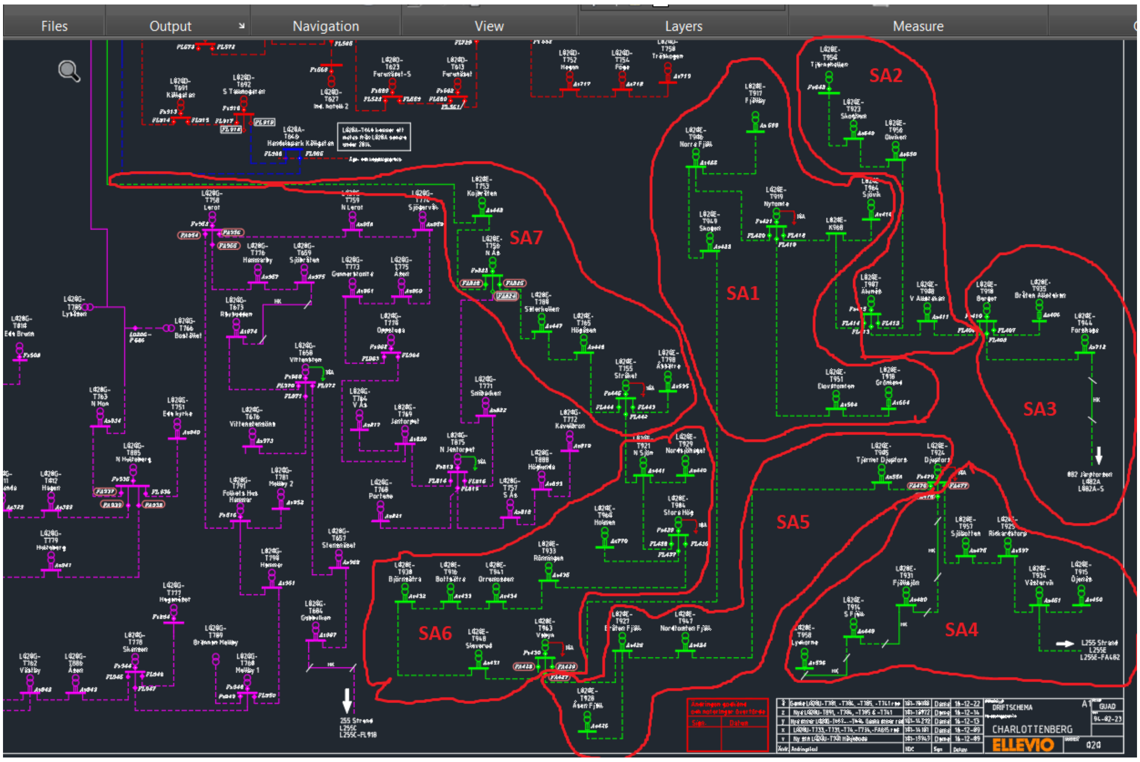

Figure B.3: Line L020-E, Scenario RCD-6

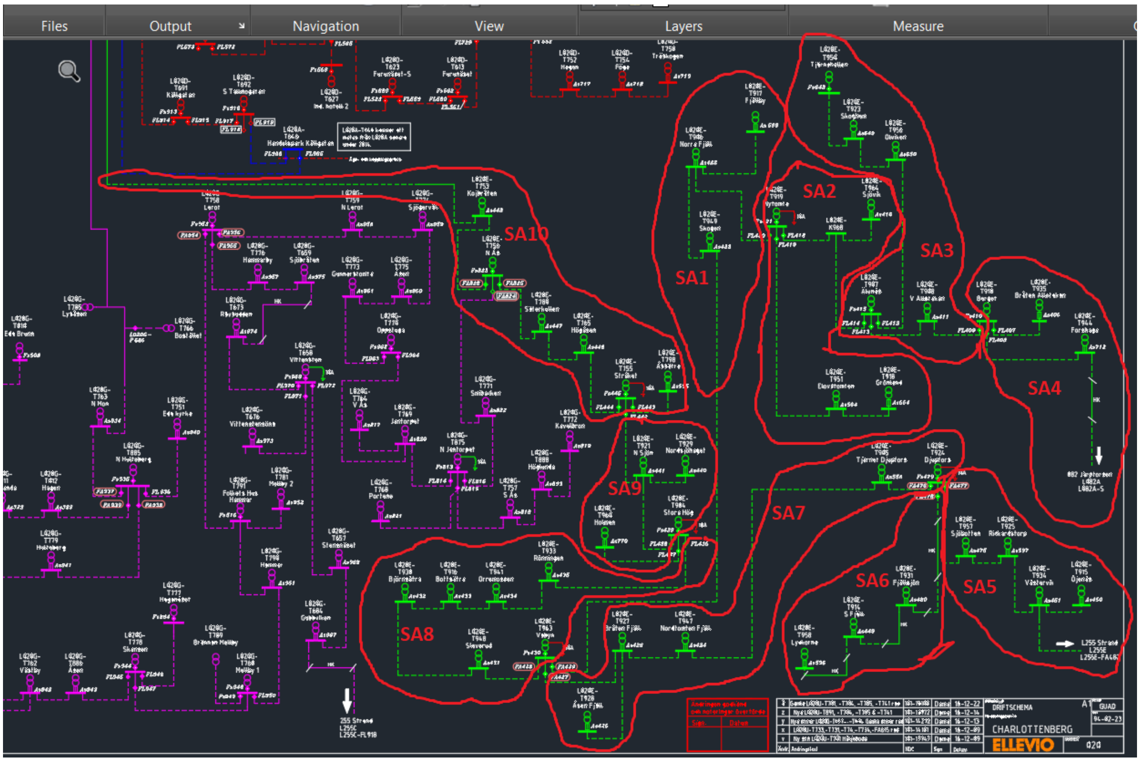

Figure B.4: Line L020-E, Scenario RCD-10

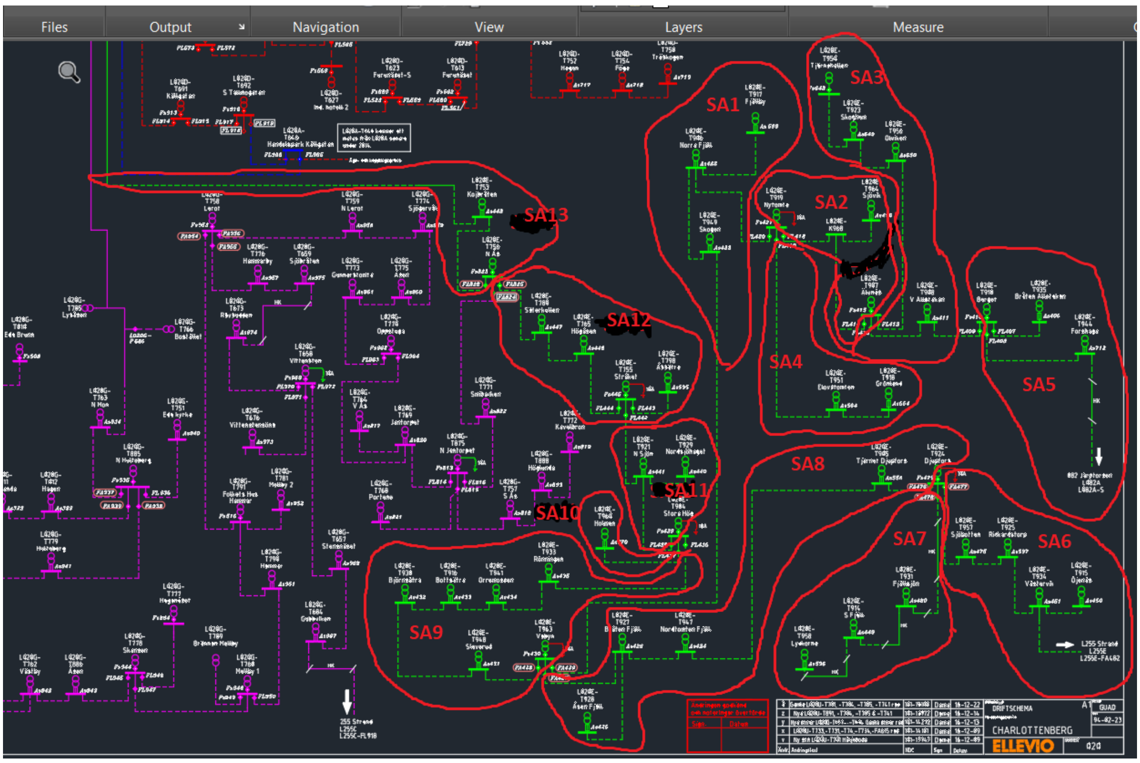

Figure B.5: Line L020-E, Scenario RCD-15

Table B.1: Line L020-E, Scenario RCD-0.

Break Area	Sum of all customer interruption duration (h)
BA16	383.8
BA14	400.6
BA11	361.4
BA10	434.2
BA9	400.6
BA8	462.2
BA7	389.4
BA6	400.6
BA4	445.4
BA2	383.8
BA1	355.8

Table B.2: Line L020-E, Scenario RCD-2.

Break Area	**Sum of all customer interruption duration (h)**
BA16	262
BA14	279
BA11	239.4
BA10	280
BA9	246
BA8	308.3
BA7	267.7
BA6	256
BA4	301
BA2	239
BA1	210.7

Table B.3: Line L020-E, Scenario RCD-4.

Break Area	Sum of all customer interruption duration (h)
BA16	200
BA14	228
BA11	177
BA10	280
BA9	246
BA8	308.3
BA7	205.2
BA6	202
BA4	247.3
BA2	203
BA1	174.7

Table B.4: Line L020-E, Scenario RCD-6.

Break Area	**Sum of all customer interruption duration (h)**
BA16	200
BA14	201
BA11	177.4
BA10	248
BA9	214
BA8	228.3
BA7	205.7
BA6	220
BA4	365.3
BA2	185
BA1	156.7

Table B.5: Line L020-E, Scenario RCD-10.

Break Area	**Sum of all customer interruption duration (h)**
BA16	181
BA14	201
BA11	158.4
BA10	200
BA9	166
BA8	228.28
BA7	154.7
BA6	166
BA4	244.3
BA2	185
BA1	156.7

Table B.6: Line L020-E, Scenario RCD-15.

Break Area	**Sum of all customer interruption duration (h)**
BA16	149
BA14	201
BA11	126.4
BA10	200
BA9	166
BA8	228.28
BA7	154.7
BA6	166
BA4	211.3
BA2	172
BA1	120.7

Table B.7: Line L020-E, Scenario RCD-24.

Break Area	**Sum of all customer interruption duration (h)**
BA16	201
BA14	164.7
BA11	126.4
BA10	200
BA9	166
BA8	228.28
BA7	154.7
BA6	166
BA4	211.3
BA2	148
BA1	120.7

Table B.8: Line L020-E, summary of results.

Scenario	CID	SAIDI [h]	Improvements compared to the previous solution, %	Improvements compared to zero installed RCDs, %
RCD-0	4417.7	15.6	-	-
RCD-2	2889.15	10.2	-34	-34
RCD-4	2471.5	8.8	-13.7	-43
RCD-6	2401.38	8.5	-3.4	-45
RCD-10	2041.32	7.2	-15.3	-54
RCD-15	1895.38	6.7	-7	-57
RCD-24	1887.08	6.66	-1	-57

C

L020-G

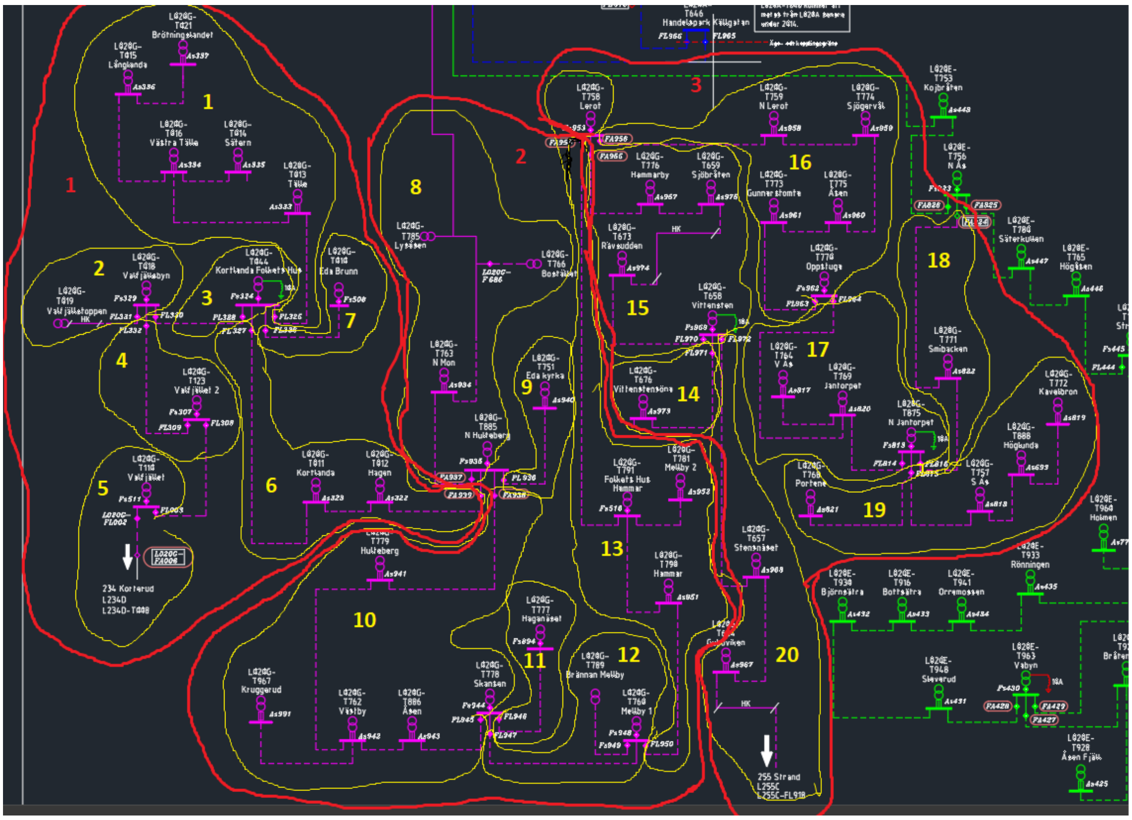

Figure C.1: Line L020-G, Scenario RCD-2

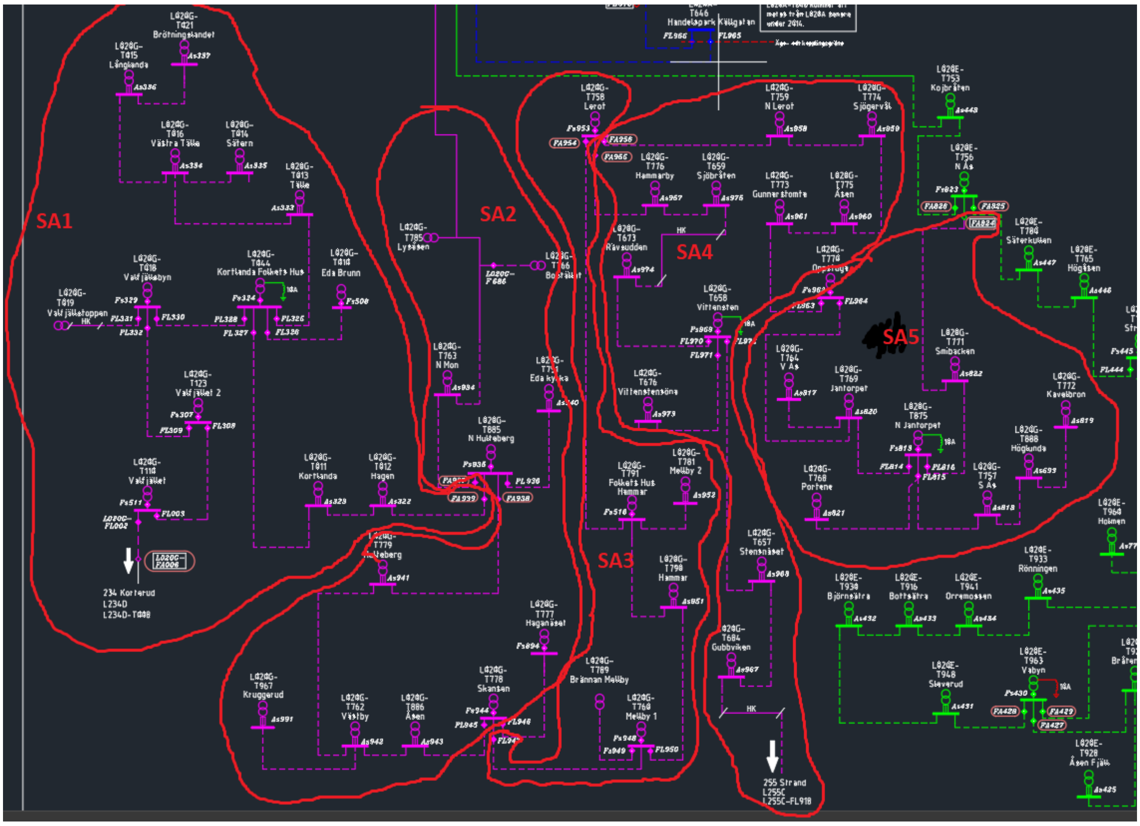

Figure C.2: Line L020-G, Scenario RCD-4

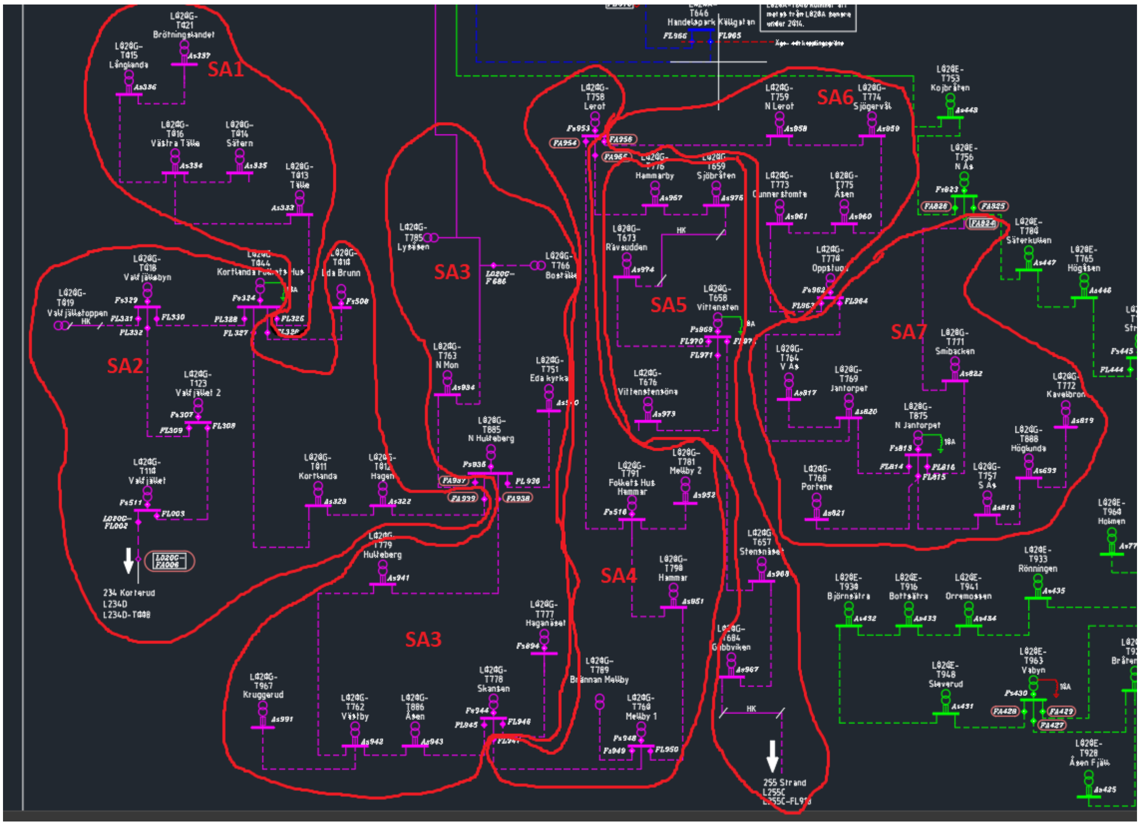

Figure C.3: Line L020-G, Scenario RCD-6

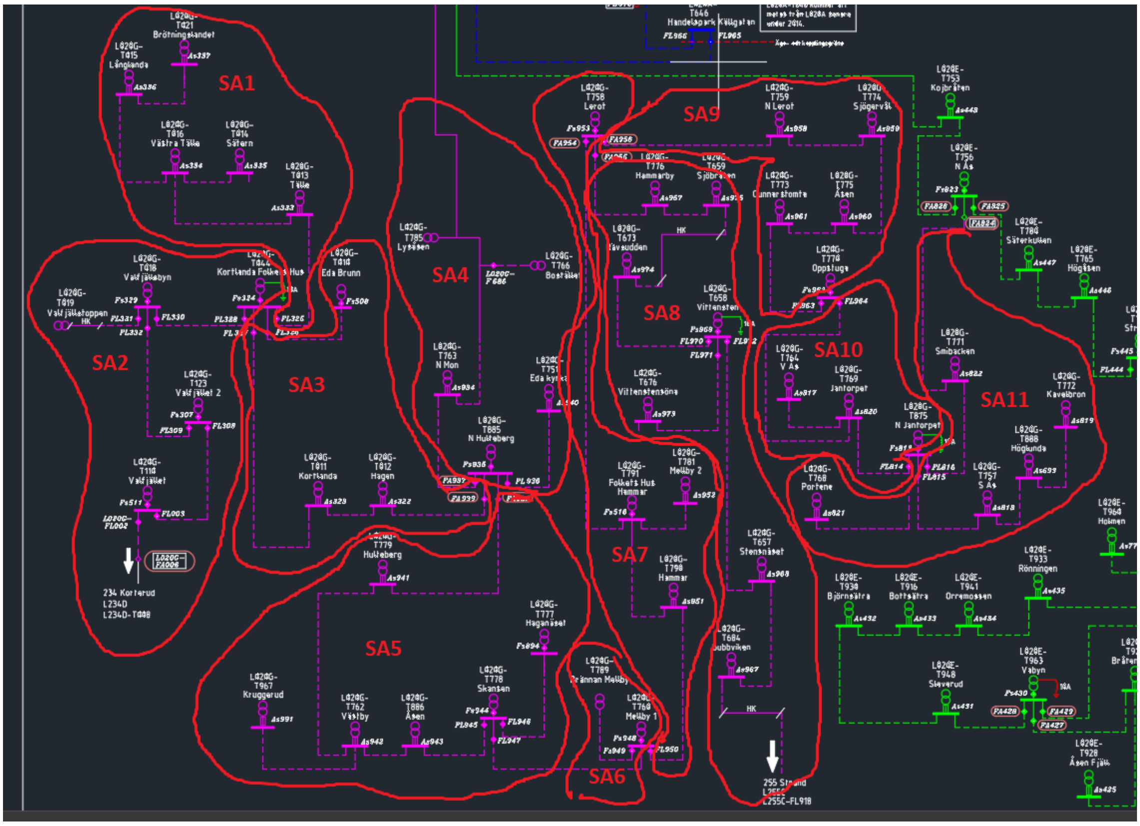

Figure C.4: Line L020-G, Scenario RCD-10

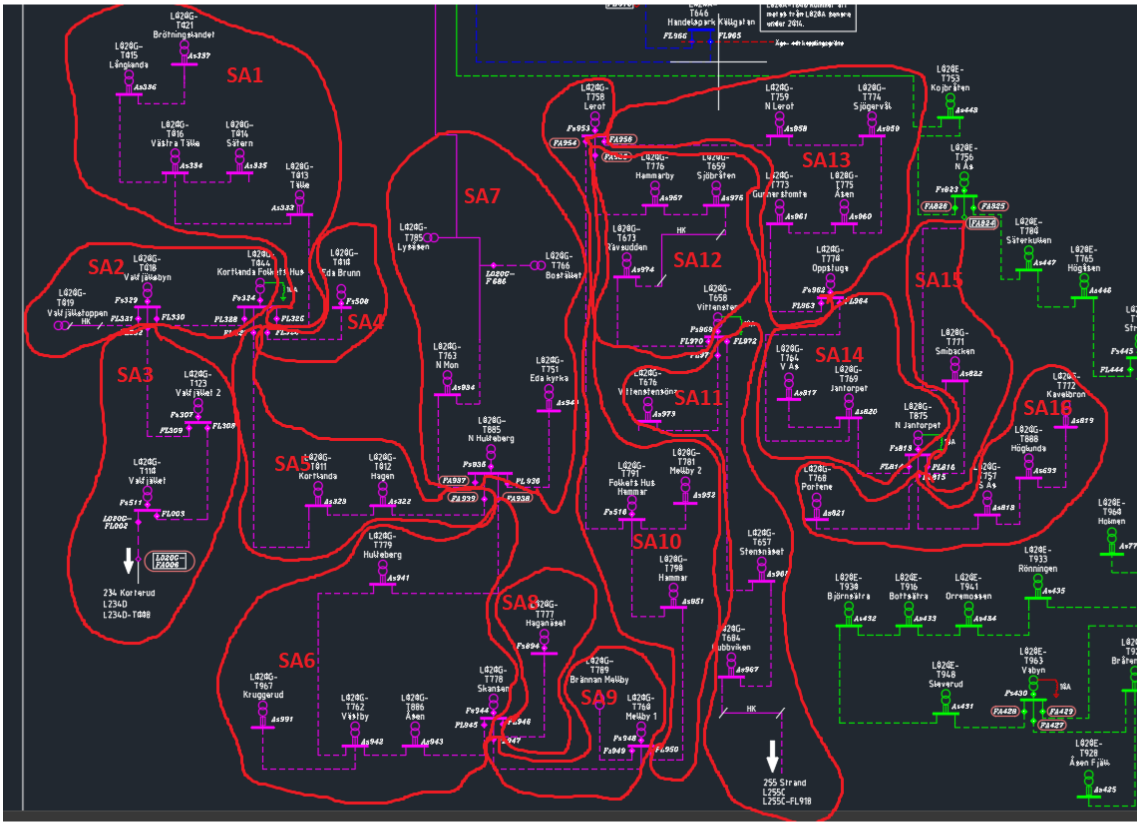

Figure C.5: Line L020-G, Scenario RCD-15

Table C.1: Line L020-G, Scenario RCD-0.

Break Area	Sum of all customer interruption duration (h)
BA2	580
BA6	508
BA10	616
BA13	706
BA19	544
BA20	460

Table C.2: Line L020-G, Scenario RCD-2.

Break Area	**Sum of all customer interruption duration (h)**
BA2	359
BA6	287
BA10	421
BA13	510
BA19	370
BA20	286

Table C.3: Line L020-G, Scenario RCD-4.

Break Area	**Sum of all customer interruption duration (h)**
BA2	359
BA6	287
BA10	349
BA13	450
BA19	280
BA20	222

Table C.4: Line L020-G, Scenario RCD-6.

Break Area	**Sum of all customer interruption duration (h)**
BA2	322
BA6	250
BA10	349
BA13	450
BA19	280
BA20	191

Table C.5: Line L020-G, Scenario RCD-10.

Break Area	**Sum of all customer interruption duration (h)**
BA2	277
BA6	203
BA10	329
BA13	378
BA19	254
BA20	191

Table C.6: Line L020-G, Scenario RCD-15.

Break Area	Sum of all customer interruption duration (h)
BA2	295
BA6	180
BA10	288
BA13	378
BA19	216
BA20	151

Table C.7: Line L020-G, Scenario RCD-33.

Break Area	Sum of all customer interruption duration (h)
BA2	252
BA6	180
BA10	288
BA13	378
BA19	216
BA20	132

Table C.8: Line L020-G, Summary of results.

Scenario	CID	SAIDI [h]	Improvements compared to the previous solution, %	Improvements compared to zero installed RCDs, %
RCD-0	3414	8.66	-	-
RCD-2	2235	5.67	-34	-34
RCD-4	1947	4.94	-13	-43
RCD-6	1842	4.67	-5	-46
RCD-10	1632	4.14	-11	-52
RCD-15	1508	3.8	-8	-56
RCD-33	1446	3.67	-3	-57

D

Additional

Table D.1: Operating dates of RCD's

Line L020-U		Line L029-E		Line L020-G	
RCD	Operating date	RCD	Operating Date	RCD	Operating date
FA457	2011-04-20	FA824	2012-10-25	FA937	2011-06-01
FA458	2011-04-20	FA825	2012-10-25	FA938	2011-06-01
FA459	2011-04-20	FA826	2012-10-25	FA939	2011-06-01
FA618	2011-02-23	FA476	2012-06-11	FA954	2011-04-28
FA623	2011-02-23	FA477	2012-06-11	FA955	2011-04-28
FA574	2011-03-10	FA478	2012-06-11	FA956	2011-04-28
-	-	FA427	2012-11-29	FA006	2011-02-24
-	-	FA428	2012-11-29	-	-
-	-	FA429	2012-11-29	-	-

Table D.2: Data for all break areas for the lines L020-U, L020-E och L020-G.

Break area	NO.Customers		
	L020-U	L020-E	L020-G
1	1	13	37
2	32	18	31
3	28	5	12
4	36	29	3
5	7	4	1
6	27	21	19
7	5	19	4
8	16	32	15
9	10	21	5
10	3	27	37
11	20	14	4
12	23	7	20
13	7	20	52
14	23	21	8
15	48	14	40
16	23	18	31
17	7	-	26
18	19	-	13
19	-	-	25
20	-	-	11