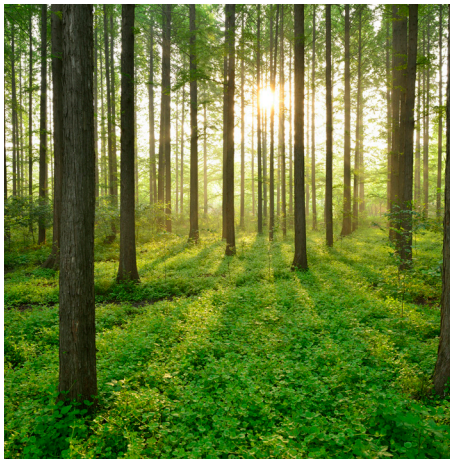
HIGH VOLTAGE EQUIPMENT RELIABILITY DATA

RAPPORT 2023-974



RISK- OCH
TILLFÖRLITLIGHETSANALYS

Energiforsk

High Voltage Equipment Reliability Data

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Förord

Programmet *Risk- och tillförlitlighetsanalys* har initierat och genomfört projektet *Tillförlitlighetsdata för högspänningskomponenter*. Kvantitativ risk- och tillförlitlighetsanalys kräver tillförlitlighetsdata för olika elektriska komponenter. Trovärdiga data har en fundamental betydelse för analysen. I dagsläget saknas tillförlitlig och heltäckande felstatistik för högspänningskomponenter. Projektet har analyserat felhändelser rapporterade av nätföretag i Sverige och utvecklar tillförlitlighetsdata för högspänningsanläggningar på nationell- och företagsnivå. Projekt-resultatet kan användas som ett branschgemensamt datastöd för risk- och tillförlitlighetsanalys för ökad kvalitet i risk- och tillförlitlighetsanalyser.

Projektet har genomförts av Ying He på Vattenfall AB, R&D.
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Summary

The reliability of a power system is assessed from the knowledge of the reliability data of individual power components contained in the system. Meaningful reliability analysis of power system requires reasonable and acceptable component reliability data. The quality of the data has the fundamental importance for the analysis.

However, the valid data are expensive to collect. The component reliability performance statistics is not easy to obtain. This report presents the high voltage equipment reliability data produced by the project "Reliability Data for High Voltage Components" within the Energiforsk program "Risk- och tillförlitlighetsanalys 2021-2025". The project analyzed a large sample size of outages caused by faults on high voltage components recorded by SvK and more than a hundred power utilities in Sweden during 2014–2021, and derived the equipment reliability data nationwide. The detailed summaries of these data are given in the report. The component reliability was also analyzed at power utility level. The fault data from Vattenfall Distribution Sweden and E.ON Energidistribution AB were studied, and the reliability data derived are also summarized in the report for each companies.

Reliability data of individual pieces of electrical components are deduced for three basic reliability statistics: 1) failure rate, expressed as failures per year per component unit (failures/yr.unit); 2) outage time or downtime or repair time, expressed in hours per failure (h/f); and 3) reliability (%). The number of components and equipment population are the basis for estimating reliability data, these statistics are also documented in the report.

The power components dealt with in the report cover operating voltages of 36 kV, 45 kV, 66 kV, 130 kV, 220 kV and 400 kV, and 10 categories of components, including: overhead line, power cable, power transformer, circuit breaker, control equipment, instrument transformer, reactor, series capacitor, shunt capacitor, and SVC device. In addition to power components the reliability statistics are also produced for power stations with operation voltages of 36 kV, 45 kV, 66 kV and 130 kV, as well as for power switching stations on voltages of 36 kV and 45 kV.

Component reliability can be affected by a number of factors. The reliability data given in this report represent component average performance statistics and should be regarded as generic. In the conclusion chapter of the report, the suggestions on how to use the reliability data produced are provided. For user's convenience Appendix A summarizes all the recommended reliability data.

Keywords

Reliability data, high voltage equipment, failure rate, repair time, availability, overhead line, cable, transformer, breaker, control equipment, capacitor, reactor, SVC device.

Sammanfattning

Kvantitativ risk- och tillförlitlighetsanalys kräver tillförlitlighetsdata för olika typer av elektriska komponenter. En meningsfull tillförlitlighetsanalys av kraftsystem kräver rimliga och acceptabla komponent tillförlitlighetsdata. Trovärdiga data har fundamental betydelse för analysen.

Men existerande felstatistik för högspänningskomponenter och tillgången till data i flertalet nätbolag upplevs som bristfälliga. I dagsläget saknas tillförlitlig felstatistik för högspänningskomponenter på branschnivå.

Denna rapport presenterar tillförlitlighetsdata för högspänningskomponenter som tagits fram av projektet ”Reliability Data for High Voltage Components” inom Energiforsks program ”Risk- och tillförlitlighetsanalys 2021-2025”. Projektet analyserade ett stort antal av avbrott orsakade av fel på högspänningskomponenter registrerade av SvK och mer än hundra elbolag i Sverige under 2014–2021. Dataunderlaget från individuella nätföretag har också studerats. Tillförlitlighetsdata på nationell nivå och för Vattenfall Eldistribution och E.ON Energidistribution AB har tagits fram och presenterats i rapporten.

Tillförlitlighetsdata som tagits fram inkluderar: felfrekvens (f/yr.unit), avbrottstid (h/f), och tillgänglighet (%). Anläggningsgrunddata och tillgångar är grund för beräkningar av tillförlitlighetsdata, även dessa data dokumenteras i rapporten.

De komponenter som behandlas i rapporten omfattar 10 komponentkategorier som inkluderar ledning, kabel, krafttransformator, brytare, styrutrustning, instrumenttransformator, spole, seriekondensator, shuntkondensator och SVC enhet, och täcker driftspänningar på 36 kV, 45 kV, 66 kV, 130 kV, 220 kV och 400 kV. Utöver komponenter tas fram även tillförlitlighetsstatistiken för regionstation eller fördelningsstation på driftspänningar 36 kV, 45 kV, 66 kV och 130 kV samt för kraftställverk på spänningar 36 kV och 45 kV.

Komponenternas tillförlitlighet kan påverkas av ett antal faktorer. Tillförlitlighetsdata som ges i denna rapport representerar komponentens genomsnittliga prestandastatistik och bör betraktas som generisk data. Rapporten avslutas med en rekommendation för hur används tillförlitlighetsdata i rapporten. För att underlätta dataanvändning sammanställs alla rekommenderade tillförlitlighetsdata i Bilaga A.

Nyckelord

Tillförlitlighetsdata, högspänningsutrustning, felfrekvens, reparationstid, tillgänglighet, luftledning, kabel, transformator, brytare, styrutrustning, kondensator, spole, SVC-utrustning.

List of content

Nomenclature

Symbol	Description
A	availability (%)
DSO	distribution system operator
ENTSO-E	European Network of Transmission System Operators for Electricity
FACTS	flexible alternating current transmission system
IGBT	Insulated Gate Bipolar Transistor
Number of failures, t=0, Number of failures with outage duration = 0	
n	number of outages observed for all the relevant component population
n_i	number of failure in i-th year
Ni	number of components operating in the i-th year
SvK	Svenska Kraftverk
t	average outage duration (hour/failure)
SAIDI	System Average Interruption Duration Index
SAIFI	System Average Interruption Frequency Index
STATCOM	Static Synchronous Compensator
SVC	Static Var Compensator
T	period of time (normally one year)
TSO	Transmission system operator
U	unavailability (%)
∑r	total outage time accumulated for all the relevant component population (hour)
ג	failure rate (failure/year.unit)

1 Introduction

A power system consists of many components, including lines, cables, transformers, etc. Component failures can lead to system failure. The component outages are the root cause of a system failure. In the reliability analysis of a power system, the system performance can be evaluated from the knowledge of the reliability data of system components.

The reliability and failure characteristics of the components are described by their reliability data. The data relates to two main aspects of the component behavior: the failure process and the restoration process.

Meaningful reliability analysis requires reasonable and acceptable data. The quality of the data and the confidence that can be placed in it has the fundamental importance for the analysis. If the quality of the data cannot be guaranteed, the results of the analysis will not make sense.

Quantitative reliability analysis requires reliability data for different types of electrical components. However the existing failure statistics for high voltage components and the availability of the data in the majority of power utilities are perceived as insufficient.

At present, there is a lack of reliable failure statistics for high voltage components at power industry level. An power branch wide data support is needed for risk and reliability analyses. Establishing and improving the power branch wide data bases at component level could lead to increased quality in risk and reliability analyses.

1.1 PURPOSE OF THE PROJECT

The purpose of the project is to improve reliability data at the component level, and deliver complemented and refined reliability data for high voltage components for risk and reliability analysis. By supplying such data, the project is intended to aid the power utilities in risk and reliability analysis of power systems.

It is expected that this project could more or less overcome problem of insufficient component reliability data. It is anticipated that the results of the project could facility the data usage and contribute to better quality of the risk and reliability analysis.

1.2 PROJECT WORK

The project is made up of three parts which are described below.

1.2.1 Work part 1: data collection

The purpose of work part 1 is to collect data and evaluate them for producing the reliability data. The data collection focuses on existing fault occurrences recorded on high voltage components for the past 5-8 years. The data collection includes:

- All types of facilities and components at the voltages of 30 kV and above that have caused power outages and are reported to Energiföretagen (Swedenergy).
- Equipment and facility basic data. e.g. population data (lengths of lines and number of components).

1.2.2 Work part 2: data analysis and producing reliability data

Part 2 focuses on studying the data bases collected and possibly supplementing data from power companies and producing reliability data at national level and for individual grid companies that have sufficient data bases. Reliability data produced include:

- Failure rate
- Repair time (downtime)
- Availability (reliability)

1.2.3 Work part 3: recommendation and reporting

Part 3 focuses on working out a recommendation for data use in risk and reliability analysis, e.g. how the generated data would be used, as well as reporting project results.

1.3 PROJECT LIMITATIONS

The project is carried out under the following constraints and limitations:

- Data from power utilities outside Sweden are not included in the data analysis.
- Planned power interruptions and outages are not included in the data analysis.
- Comparisons of the produced reliability data with other data sources are not made in the project.
- Reliability data for temporary interruptions (normally shorter than 3 minutes) are not handled in the project.
- Sensitivity analysis of the produced reliability data is not performed in the project.

2 Component Reliability Data and Its Acquisition

Any discussion of quantitative risk and reliability analysis invariably leads to a discussion of the component reliability data. From a reliability perspective, nearly all of the information needed to create reliability model for a power system is contained in power component information.

Valid and useful data are expensive to obtain, but it should be recognized in the long term that it could be even more expensive not to collect them. The knowledge of the reliability of electric equipment is important consideration in the system planning and operation, without such knowledge it could be impossible to conduct meaningful risk and reliability studies on power systems.

This chapter focuses on concepts and definitions of component reliability data and its acquisition.

2.1 COMPONENT RELIABILITY DATA

Component reliability data describe the reliability of the electric equipment. These data can be established from the operational field data, and then used in subsequent system planning and analysis, creating a feedback loop. These data are valuable for the following reasons:

- Establish the feedback of data from the network operation field, and provide an assessment of network equipment past performance data.
- Monitor the network equipment, and identify the chronological changes in the equipment performance.
- Help to identify network equipment weak areas and need for reinforcement.
- Reflect and respond to the equipment stochastic behavior, and allow this feedback information to be used in system analysis and in predicting the values in future system planning.

The component reliability data reflect the two processes involved in component behavior, namely the failure process and the restoration process. The data associated with these two processes can be described by the following three kinds of basic statistics:

- Failure rate, often called failure frequency, expressed as number of failures per year per component, for lines, failures per year per unit length.
- Outage duration, often called downtime or unavailable time or restoration time, to repair or replace a component after it has failed in service, expressed in hours per failure occurrence.
- Unavailability, the production of failure rate and downtime in year expressed as a percentage.

2.2 COMPONENT RELIABILITY DATA ACQUISITION AND PROCESSING

Component reliability data are established in one of two ways: from component experimental testing and from operational field data. The first is only applicable for small-scale components. The second method has to be used for all other situations.

Electrical component reliability data are normally obtained from field outage records and equipment failure reports. Data processing comprises two activities: field data collection and data analysis. The field data are firstly collected by operation and maintenance personnel documenting the details of failures as they occur, together with the associated outage durations.

The field data are then analyzed to produce the statistical performance reliability data. These statistical data are updated by the entry of subsequent new data. To derive the reliability data, the failure events are counted within each component failure category in a defined period of time, and the failure rate, average outage duration and unavailability can then be calculated.

In order to aid power utilities in reporting and analyzing failure events of power systems and performing reliability analysis, IEEE and Cigre have issued a number of standards and guidelines [2-4]. These standards and guidelines propose and recommend procedures for collecting, compiling, analyzing and presenting data. They provide also definitions and methods by which component reliability data can be determined. Under the guidance of the standards, the component statistic performance indices can be calculated for high voltage components based on the outage data collected. The following sub-sections describe how to estimate these reliability indices.

2.2.1 Failure rate calculation

Failure rate has been the most utilized measure of reliability. It is based on the count of the number of fault occurrences. Component failure rate is defined as the number of random (unscheduled) occurrences of failure of a component to perform its intended function over a period of time.

Using this definition, failure rate is expressed in term of failures per component of similar characteristics having been in service for a different length of time. In this case, the failure rate for this type of component is estimated by dividing the total number of failures experienced by the total service years of all components of this type:

$$\lambda = \frac{n_1 + n_2 + \cdots + n_i}{(N_1 + N_2 + \cdots + N_i) \cdot T} \cdot 100\%$$

Where:

λ = failure rate (failure/year.unit)

n_i = number of failure in i-th year

Ni = number of components operating in the i-th year

T = period of time (normally one year).

According to IEEE standard, failure rate should be calculated for forced outages for statistical purposes [4]. Failure rate is calculated as the ratio of the number failures with forced outages of a given population over a given period of time, to the number of accumulated service years for all components in that population.

Failures (components fail to perform their function) with scheduled outage occur when the component is deliberately taken out of service at a selected time. These unforced (planned) outages are not included in the calculation of the failure rate. Some defects may arise and imperfection may be corrected without taking the component out of service. These defects and imperfections are not counted as failure events.

For forced outages IEEE standard designates two types of failures: permanent and transient forced outages. They are also generally known as damaged failures and non-damaged failures. The transient forced outage whose cause is self-clearing so that the affected components are usually restored to service automatically by reclosure or switching operations without repair after the failure. The associated outage duration is short. The failure rate related to transient forced outages are not considered in the calculations of this report.

2.2.2 Outage duration calculation

Outage duration is the time period from the initiation of an outage occurrence until the component affected is returned to the service. It is equal to the sum of times required for completely restoring the component to service, i.e. any time required for switching, dismantling, repair, or replacement of the component that results in restoring the component to normal service.

Outage durations are commonly summarized for specific types of outages, for example, component related permanent forced outage duration. The average outage duration is estimated by the total time divided by the number of outages:

$$t \cong \frac{\sum r}{n}$$

Where:

t = average outage duration (hour/failure)

∑r = total outage time accumulated for all the relevant component population (hour)

n = number of outages observed for all the relevant component population

2.2.3 Unavailability (Availability) calculation

Unavailability is defined as customer hours of unavailable service divided by customer hours demanded, and can be calculated by:

$$U = \frac{\lambda \cdot t}{8760}$$

$$A = 100\% - U$$

Where 8760 is the number of hours in a calendar year

U = unavailability (%)

A = availability (%)

2.2.4 Data processing

The data are processed according to component types and voltage levels in both national and company-wide which has sufficient data bases. The power companies considered include Svenska kraftnät (SvK), Vattenfall Distribution Sweden and E.ON Energidistribution AB. Considering the voltage levels and equipment categories used in the power utilities for outage reporting, as well as the data available to the project, the following classifications are made in the project for deducing the statistics:

Voltage levels:

- 36 kV
- 45 kV
- 66 kV
- 132 kV
- 220- 400 kV

Component categories:

- Overhead line
- Power cable
- Power transformer
- Circuit breaker
- Control equipment
- Instrument transformer
- Reactor
- Capacitor
- SVC device
- Power station
- Power switching station

3 Data Sources

To produce component reliability data requires information describing outages. The outage filed data are usually first collected at the network companies by documenting the details of outages as they occur. These field data are then analyzed to create statistical indices.

The electric power utilities in Sweden record and document the outages together with the associated details. Their outage statistics are annually reported to the national database, maintained by Energiföretagen. This national database is a comprehensive grid operation interruption and outage reporting computer system. It is used to generate the national outage statistics, and gives annual reliability indices such as SAIFI, SAIDI, and the interruption cause contributions for Sweden as a whole.

Over 100 electrical power utilities in Sweden participate in the data collection and reporting of the national interruption and outage statistics. For this project the outage occurrences reported to Energiföretagen in the period of 2014-2021 are used as basis for generating reliability data for all Swedish DSOs (distribution system operator).

Transmission system operators (TSOs) in Nordic and Baltic countries collect and report the grid disturbances and faults to European Network of Transmission System Operators for Electricity ENTSO-E and produce Nordic and Baltic Grid Disturbance Statistics. The disturbances reported by Svenska Kraftnät (SvK) during 2018-2021 are also used in the project for generating reliability data for SvK statistics.

3.1 ALL SWEDISH DSOS DATA

During the period of 2014-2021 all Swedish DSOs reported totally 5973 interruption and outage occurrences on operating voltages 30- 400 kV, which are listed in table 3.1. The database also contains the following information associated with each outage occurrence:

- The time when an outage occurs
- The time when the system is restored to service
- The faulted distribution equipment.

For high voltage systems, the national database covers the following system operating voltages:

- 36 kV
- 45 kV
- 66 kV
- 132 kV

The major high voltage components included in the national database are as follows:

- Overhead line
- Power cable
- Power transformer
- Circuit breaker
- Power station
- Power switching stations

1 Table 3.1: Outage occurrences on 30-400 kV high voltage equipment during 2014-2021

Year	Outage occurrences reported to Energiföretagen by all Swedish DSOs (All DSOs)	Outage occurrences recorded by Svenska Kraftnät (SvK)	Outage occurrences reported by Vattenfall Distribution Sweden (Vattenfall)	Outage occurrences reported by E.ON Energidistribution AB (E.ON)
2014	464		37	202
2015	574		35	117
2016	548		50	144
2017	575		25	164
2018	697	376	50	205
2019	765	426	116	254
2020	440	396	37	216
2021	1910	489	36	

3.2 SVK DATA

During 2018-2021 totally 1687 grid disturbances on SvK 220-400 kV power systems were collected. The number of disturbances reported for each year is listed 1 Table 3.1: Outage occurrences on 30-400 kV high voltage equipment during 2014-2021 The type of a system component is determined by its dominant component. The categories of system units included in SvK disturbance report are of the following:

- Overhead line
- Power cable
- Power transformer
- Circuit breaker
- Control equipment
- Instrument transformer
- Reactor
- Series capacitor
- Shunt Capacitor
- SVC device

3.3 EQUIPMENT POPULATION DATA

To deduce component reliability data requires two types of data: outage data and equipment population data. The number of outages and component population data are the basis for estimating component reliability data. The population data are collected together with the outage data, which are associated with the power system components with operating voltages of 36 kV and above. The population data collected also cover the power equipment owed by SvK. The population data used in the project for each component category are presented together with the related component reliability data in the subsequent chapters.

4 Reliability Data of Overhead Lines

Overhead lines constitute one of the main parts of a power system. Their reliability parameters are of prime importance for power system reliability analysis. A knowledge of the reliability of power lines is an essential consideration in the planning and design of power systems.

This chapter summarizes the reliability data for overhead lines deduced from outage data collected over a period of 8 years between 2014 and 2021. The chapter is divided into 6 parts, consisting the reliability data for the following voltage levels:

- 220-400 kV
- 130 kV
- 66 kV
- 45 kV
- 36 kV

The last part of the chapter gives the recommended statistics for overhead lines based on the reliability data derived.

The reliability data were also studied at power utility level. Apart from the study of the data from SvK, the outage data submitted by two large companies: Vattenfall Distribution Sweden and E.ON Energidistribution AB were analyzed as well to produce the reliability data the company wide. The resulting data for these individual companies are summarized in the subsequent sections.

4.1 220–400 KV OVERHEAD LINES

During 2018-2021 there were totally 268 faults on 220-400 kV overhead lines recorded by SvK, among which 130 faults on 220 kV and 138 faults on 400 kV overhead liens. Table 4.1.1 presents the length of the overhead lines and the number of faults in 2021, and the 10-year annual average number of faults in 2012-2021 [1]. Table 4.1.2 presents the outage duration of 220-400 kV overhead lines based report from SvK.

It should be mentioned that for some of faults there were no fault ending time recorded, thus no complete information available for faults duration. Those faults were not included in the calculation. Based on the number of faults and outage duration, the reliability data for the overhead lines are deduced. The results are presented in table 4.1.3.

2 Table 4.1.1: Length of 220-400 kV overhead lines and number of failures

Equipment	Number of km in 2021	Number of failures, in 2021	Number of failures, 10-year annual average in 2012-2021	Based data from
220 kV overhead line	3466,8	30	28,3	SvK
400 kV overhead line	9542	49	35,9	SvK

3 Table 4.1.2: Outage duration of 220-400 kV overhead lines based data from SvK

Eqipment	Year	Number of failures recorded with outage time	Total outage time (h)	Outage time (h/f)
220 kV overhead line	2018	42	168,10	4,00
	2019	37	62,68	1,69
	2020	21	11,30	0,54
	2021	30	210,00	7,00
400 kV overhead line	2018	31	179,82	5,80
	2019	32	233,22	7,29
	2020	26	14,97	0,58
	2021	49	143,00	2,92

4 Table 4.1.3: Reliability data of 220-400 kV overhead lines

Equipment	Failure rate in 2021 (f/yr.km)	Failure rate,10-year annual average in 2012-2021 (f/yr.km)	Outage time in 2021 (h/f)	Outage time, 4-year average in 2018-2021 (h/f)	Availability in 2021	Availability, 4-year average in 2018-2021	Based data from
220 kV overhead line	0,00865	0,00730	7,00	3,48	99,99931%	99,99971%	SvK
400 kV overhead line	0,00514	0,00340	2,92	4,14	99,99983%	99,99984%	SvK

4.2 130 KV OVERHEAD LINES

The reliability performance of 130 kV overhead lines were estimated based on outage data from two data sources: SvK data and all Swedish DSO data. The results of the estimation are presented in the following sub-sections.

For 130 kV overhead lines the outage records are in principle good at Vattenfall Distribution Sweden and E.ON Energidistribution AB. These outage data are

analyzed as well to produce the reliability data at the company level, which are also summarized in the following sections.

4.2.1 SvK statistics

The ENTSO-E, the European Network of Transmission System Operators for Electricity, is the association for the cooperation of the European transmission system operators (TSOs), and is responsible for the secure and coordinated operation of Europe's electricity systems. In addition to its core in technical cooperation, the ENTSO-E also collects and maintains interruption data from the member TSOs, and publishes grid disturbance statistics for Nordic and Baltic 100–420 kV AC power grids, as well as gives a deeper dive into the statistics of individual components used in the grids. According to the outage data reported to the ENTSO-E by SvK [1], the length of 130 kV overhead lines and the number of faults in 2021, and the 10-year annual average of the number of faults in 2012–2021 are summarized in table 4.2.1. The outage duration and the reliability data of 130 kV overhead lines are given in table 4.2.2 and table 4.2.3 respectively.

5 Table 4.2.1: Length of 130 kV overhead lines and number of failures

Equipment	Number of km in 2021	Number of failures, in 2021	Number of failures, 10-year annual average in 2012-2021	Based data from
Overhead line 130 kV	15143,2	253	214,5	SvK

6 Table 4.2.2: Outage duration of 130 kV overhead lines based data from SvK

Eqipment	Year	Number of failures recorded with outage time	Total outage time (h)	Outage time (h/f)
130 kV overhead line	2018	95	220,37	2,32
	2019	26	27,77	1,07
	2020	19	5,83	0,31
	2021	112	189,00	1,69

7 Table 4.2.3: Reliability data of 130 kV overhead lines

Equipment	Failure rate in 2021 (f/yr.km)	Failure rate, 10-year annual average in 2012-2021 (f/yr.km)	Outage time in 2021 (h/f)	Outage time, 4-year average in 2018-2021 (h/f)	Availability in 2021	Availability, 4-year annual average in 2018-2021	Based data from
130 kV overhead line	0,01671	0,01420	1,69	1,76	99,99968%	99,99972%	SvK

4.2.2 All Swedish DSO statistics

In outage reporting to the national database at Energiföretagen by Swedish DSOs, the overhead lines are divided into two categories:

- overhead line, bare (friledning oisolerad)
- overhead line, isolated (friledning isolerad).

Since no complete data available for length of the overhead lines isolated, the reliability data are deduced only for overhead lines bare. Table 4.2.4 and table 4.2.5 summarize the failure rate, outage time and reliability data for 130 kV overhead lines bare.

A comparison of the reliability statistics for 130 kV overhead lines based data both from SvK and from Swedish DSOs shows significant differences. The statistics based on the data from SvK give higher failure rate and shorter outage duration than that giving from the data of Swedish DSOs. This may be dependent on that the outages reported by SvK include not only permanent faults but also temporary and short duration ones, while the outages reported by Swedish DSOs are dominated by sustainable permanent outages.

It is noticed that SvK does not classify overhead lines further to sub-categories. The faults on overhead lines contain faults both on overhead lines bare and on overhead lines isolated.

8 Table 4.2.4: Failure rate and outage time of 130 kV overhead lines bare

Equipment	Year	Number of km	Number of failures with outage duration > 0	Total outage time (h)	Failure rate (f/yr.km)	Outage time (h/f)	Based data from
130 kV overhead line bare (Friledning, oisolerad)	2014		20	37,72		1,89	All Swedish DSOs
	2015		13	22,12		1,70	
	2016		16	21,78		1,36	
	2017		27	87,7		3,25	
	2018	12642,4	29	96,33	0,00229	3,32	
	2019	12594,4	48	318,88	0,00381	6,64	
	2020	12644,5	19	306,42	0,00150	16,13	
	2021	13415,3	17	40,9	0,00127	2,41	

9 Table 4.2.5: Reliability data of 130 kV overhead lines bare

Equipment	Failure rate in 2021 (f/yr.km)	Failure rate, 8-year annual average in 2014-2021 (f/yr.km)	Outage time in 2021 (h/f)	Outage time, 8-year average in 2014-2021 (h/f)	Availability in 2021	Availability, 8-year annual average in 2014-2021	Based data from
130 kV overhead line bare (Friledning, oisolerad)	0,00127	0,00184	2,41	4,93	99,99997%	99,99990%	All Swedish DSOs

4.2.3 Vattenfall statistics

Analysis of the outage data submitted by Vattenfall Distribution Sweden gives the reliability data shown in table 4.2.6 and table 4.3.7 below. As no complete fault data available for 2014-2018, the reliability data for 130 kV overhead lines bare could be obtained only for 3-year period in 2019-2021.

10 Table 4.2.6: Failure rate and outage time of 130 kV overhead lines bare of Vattenfall

Equipment	Year	Number of km	Number of failures with outage duration > 0	Total outage time (h)	Failure rate (f/yr.km)	Outage time (h/f)	Based data from
130 kV overhead line bare of Vattenfall (Friledning, oisolerad)	2014						Vattenfall
	2015	6534,6					
	2016	6534,6					
	2017	6945,6					
	2018	7289,3					
	2019	7289,3	1	1,40	0,00014	1,40	
	2020	7289,3	1	0,17	0,00014	0,17	
	2021	7427,0	1	0,30	0,00013	0,30	

11 Table 4.2.7: Reliability data of 130 kV overhead lines bare of Vattenfall

Equipment	Failure rate in 2021 (f/yr.km)	Failure rate, 3-year annual average in 2019-2021 (f/yr.km)	Outage time in 2021 (h/f)	Outage time, 3-year average in 2019-2021 (h/f)	Availability in 2021	Availability, 3-year annual average in 2019-2021	Based data from
130 kV overhead line bare of Vattenfall (Friledning, oisolerad)	0,00013	0,00014	0,30	0,62	99,9999995%	99,999999%	Vattenfall

4.2.4 E.ON Energidistribution AB statistics

This section presents overhead line data for E.ON Energidistribution AB. Table 4.2.8 presents the length of overhead lines and failure rates and outage duration. Table 4.2.9 shows reliability data deduced for E.ON's 130 kV overhead lines bare.

12 Table 4.2.8: Failure rate and outage time of 130 kV overhead lines bare of E.ON

Equipment	Year	Number of km	Number of failures with outage duration > 0	Total outage time (h)	Failure rate (f/yr.km)	Outage time (h/f)	Based data from
130 kV overhead line bare of E.ON (Friledning, oisolerad)	2014		15	20,23		1,35	E.ON Energidistribution AB
	2015		7	13,87		1,98	
	2016		10	10,87		1,09	
	2017		13	78,70		6,05	
	2018	4967,67	20	73,78	0,00403	3,69	
	2019	5013,09	37	309,32	0,00738	8,36	
	2020	5074,73	13	299,93	0,00256	23,07	
	2021	5196,18					

13 Table 4.2.9: Reliability data of E.ON's 130 kV overhead lines bare of E.ON

Equipment	Failure rate in 2020 (f/yr.km)	Failure rate, 3-year annual average in 2018-2020 (f/yr.km)	Outage time in 2020 (h/f)	Outage time, 7-year average in 2014-2020 (h/f)	Availability in 2020	Availability, 3-year annual average in 2018-2020	Based data from
130 kV overhead line bare of E.ON (Friledning, oisolerad)	0,00256	0,00324	23,07	7,01	99,99933 %	99,99974 %	E.ON Energidistribution AB

4.3 66 KV OVERHEAD LINES

This section deals with reliability data of overhead lines on 66 kV. The study of the data submitted by the DSOs shows that the most majority of overhead lines on 66 kV are overhead lines bare, since very few faults on overhead lines isolated are reported and there are no line length data available for overhead lines isolated.

The study has generated statistics for all Swedish DSO and E.ON Energidistribution AB. The reliability data for Vattenfall Distribution Sweden could not be generated due to the uncomplete data for the company.

4.3.1 All Swedish DSO statistics

Table 4.3.1 summarizes the failure rate and outage duration, and table 4.3.2 presents the reliability data of 66 kV overhead lines bare.

14 Table 4.3.1: Failure rate and outage time of 66 kV overhead lines bare

Equipment	Year	Number of km	Number of failures with outage duration > 0	Total outage time (h)	Failure rate (f/yr.km)	Outage time (h/f)	Based data from
66 kV overhead line bare, (Friledning, oisolerad)	2014		5	4,48		0,90	All Swedish DSOs
	2015		7	4,62		0,66	
	2016		6	5,65		0,94	
	2017		11	30,05		2,73	
	2018		7	14,57		2,08	
	2019	2261,88	11	185,90	0,00486	16,90	
	2020	2258,08	8	48,23	0,00354	6,03	
	2021	2024,10	7	2,63	0,00346	0,38	

15 Table 4.3.2: Reliability data of 130 kV overhead lines bare

Equipment	Failure rate in 2021 (f/yr.km)	Failure rate, 3-year annual average in 2019-2021 (f/yr.km)	Outage time in 2021 (h/f)	Outage time, 8-year average in 2014-2021 (h/f)	Availability in 2021	Availability, 3-year annual average in 2014-2021	Based data from
66 kV overhead line bare, (Friledning, oisolerad)	0,00346	0,00355	0,38	4,78	99,99999%	99,99981%	All Swedish DSOs

4.3.2 E.ON Energidistribution AB statistics

This section presents the reliability statistics related to the disturbances on 66 kV overhead lines bare of E.ON Energidistribution AB. Table 4.3.3 shows the failure rate and outage time, and table 4.3.4 the reliability data.

16 Table 4.3.3: Failure rate and outage time of 66 kV overhead lines bare of E.ON Energidistribution AB

Equipment	Year	Number of km	Number of failures with outage duration > 0	Total outage time (h)	Failure rate (f/yr.km)	Outage time (h/f)	Based data from
66 kV overhead line bare of E.ON (Friledning, oisolerad)	2014		4	3,42		0,86	E.ON Energidistribution AB
	2015		5	3,72		0,74	
	2016		2	0,40		0,20	
	2017		6	26,17		4,36	
	2018		5	12,27		2,45	
	2019	620,44	9	164,47	0,01451	18,27	
	2020	620,44	6	46,33	0,00967	7,72	
	2021	623,78					

17 Table 4.3.4: Reliability data of 66 kV overhead lines bare of E.ON Energidistribution AB

Equipment	Failure rate in 2020 (f/yr.km)	Failure rate, 2-year annual average in 2019-2020 (f/yr.km)	Outage time in 2020 (h/f)	Outage time, 7-year average in 2014-2020 (h/f)	Availability in 2020	Availability, 3-year annual average in 2018-2020	Based data from
66 kV overhead line bare of E.ON (Friledning, oisolerad)	0,00967	0,00850	7,72	6,94	99,99915%	99,99933%	E.ON Energidistribution AB

4.4 45 KV OVERHEAD LINES

This section summarizes reliability statistics for 45 kV overhead lines. Table 4.4.1 and table 4.4.2 show reliability data of all Swedish DSO statistics, table 4.4.3 and table 4.4.4 for Vattenfall Distribution Sweden, and table 4.4.5 and table 4.4.6 for E.ON Energidistribution AB.

4.4.1 All Swedish DSO statistics

18 Table 4.4.1: Failure rate and outage time of 45 kV overhead lines bare

Equipment	Year	Number of km	Number of failures with outage duration > 0	Total outage time (h)	Failure rate (f/yr.km)	Outage time (h/f)	Based data from
45 kV overhead line bare (Friledning, oisolerad)	2014	8784,68	84	134,58	0,00956	1,60	All Swedish DSOs
	2015		54	169,65		3,14	
	2016		44	52,88		1,20	
	2017	8839,84	9	50,38	0,00102	5,60	
	2018	11572,18	7	14,57	0,00060	2,08	
	2019	9835,13	111	715,00	0,01129	6,44	
	2020	9283,93	64	523,47	0,00689	8,18	
	2021	9961,97	70	151,18	0,00703	2,16	

19 Table 4.4.2: Reliability data of 45 kV overhead lines bare

Equipment	Failure rate in 2021 (f/yr.km)	Failure rate, 6-year annual average in 2014-2021 (f/yr.km)	Outage time in 2021 (h/f)	Outage time, 8-year average in 2014-2021 (h/f)	Availability in 2021	Availability, 6-year annual average in 2014-2021	Based data from
45 kV overhead line bare, (Friledning, oisolerad)	0,00703	0,00570	2,16	4,09	99,99983%	99,99973%	All Swedish DSOs

4.4.2 Vattenfall statistics

20 Table 4.4.3: Failure rate and outage time of 45 kV overhead lines bare of Vattenfall Distribution Sweden

Equipment	Year	Number of km	Number of failures with outage duration > 0	Total outage time (h)	Failure rate (f/yr.km)	Outage time (h/f)	Based data from
45 kV overhead line bare of Vattenfall (Friledning, oisolerad)	2014	5580,93					Vattenfall
	2015		12	41,65		3,47	
	2016						
	2017	5580,93					
	2018	6389,30	11	19,08	0,00172	1,73	
	2019	5034,30	27	84,02	0,00536	3,11	
	2020	5034,30	15	50,38	0,00298	3,36	
	2021	4973,00	15	17,52	0,00302	1,17	

21 Table 4.4.4: Reliability data of 45 kV overhead lines bare of Vattenfall Distribution Sweden

Equipment	Failure rate in 2021 (f/yr.km)	Failure rate, 4-year annual average in 2018-2021 (f/yr.km)	Outage time in 2021 (h/f)	Outage time, 5-year average in 2015-2021 (h/f)	Availability in 2021	Availability, 4-year annual average in 2018-2021	Based data from
45 kV overhead line bare of Vattenfall, (Friledning, oisolerad)	0,00302	0,00491	1,17	1,90	99,99996%	99,99989%	Vattenfall

4.4.3 E.ON Energidistribution AB statistics

22 Table 4.4.5: Failure rate and outage time of 45 kV overhead lines bare of E.ON Energidistribution AB

Equipment	Year	Number of km	Number of failures with outage duration > 0	Total outage time (h)	Failure rate (f/yr.km)	Outage time (h/f)	Based data from
45 kV overhead line bare of E.ON (Friledning, oisolerad)	2014		31	85,43		2,76	E.ON Energidistribution AB
	2015		12	95,65		7,97	
	2016		14	16,12		1,15	
	2017		9	50,38		5,60	
	2018	3767,67	27	159,67	0,00717	5,91	
	2019	3485,62	49	604,28	0,01406	12,33	
	2020	3478,10	22	166,77	0,00633	7,58	
	2021	3466,98					

23 Table 4.4.6: Reliability data of 45 kV overhead lines bare of E.ON Energidistribution AB

Equipment	Failure rate in 2020 (f/yr.km)	Failure rate, 3-year annual average in 2018-2020 (f/yr.km)	Outage time in 2020 (h/f)	Outage time, 7-year average in 2014-2020 (h/f)	Availability in 2020	Availability, 3-year annual average in 2018-2020	Based data from
45 kV overhead line bare of E.ON (Friledning, oisolerad)	0,00633	0,00660	7,58	7,18	99,99945%	99,99946%	E.ON Energidistribution AB

4.5 36 KV OVERHEAD LINES

The reliability statistics for 36 kV overhead lines are derived in the same way as that for 45 kV lines. Due to uncomplete line data for Vattenfall Distribution Sweden the reliability data could not be obtained for the company.

Table 4.5.1 and table 4.5.2 show reliability statistics for all Swedish DSOs, table 4.5.3 and table 4.5.4 for E.ON Energidistribution AB.

4.5.1 All Swedish DSO statistics

24 Table 4.5.1: Failure rate and outage time of 36 kV overhead lines bare

Equipment	Year	Number of km	Number of failures with outage duration > 0	Total outage time (h)	Failure rate (f/yr.km)	Outage time (h/f)	Based data from
36 kV overhead line bare, (Friledning, oisolerad)	2014		11	35,07		3,19	All Swedish DSOs
	2015		9	9,05		1,01	
	2016		5	50,78		10,16	
	2017	779,41	31	75,53	0,03977	2,44	
	2018	773,66	20	30,03	0,02585	1,50	
	2019		8	19,98		2,50	
	2020		9	4,47		0,50	
	2021	725,97	12	146,62	0,01653	12,22	

25 Table 4.5.2: Reliability data of 36 kV overhead lines bare

Equipment	Failure rate in 2021 (f/yr.km)	Failure rate, 3-year annual average in 2017-2021 (f/yr.km)	Outage time in 2021 (h/f)	Outage time, 8-year average in 2014-2021 (h/f)	Availability in 2021	Availability, 3-year annual average in 2017-2021	Based data from
36 kV overhead line bare (Friledning, oisolerad)	0,01653	0,01728	12,22	3,54	99,99769%	99,99930%	All Swedish DSOs

4.5.2 E.ON Energidistribution AB statistics

26 Table 4.5.3: Failure rate and outage time of 36 kV overhead lines bare of E.ON Energidistribution AB

Equipment	Year	Number of km	Number of failures with outage duration > 0	Total outage time (h)	Failure rate (f/yr.km)	Outage time (h/f)	Based data from
36 kV overhead line bare of E.ON (Friledning, oisolerad)	2014	23,01	5	16,15		3,23	E.ON Energidistribution AB
	2015		1	0,07		0,07	
	2016		1	1,00		1,00	
	2017	23,01	5	8,62		1,72	
	2018	23,01	7	3,72	0,30422	0,53	
	2019	23,01	5	17,37	0,21730	3,47	
	2020	23,01	4	1,33	0,17384	0,33	
	2021	25,29					

27 Table 4.5.4: Reliability data of 36 kV overhead lines bare of E.ON Energidistribution AB

Equipment	Failure rate in 2020 (f/yr.km)	Failure rate, 3-year annual average in 2018-2020 (f/yr.km)	Outage time in 2020 (h/f)	Outage time, 7-year average in 2014-2020 (h/f)	Availability in 2020	Availability, 3-year annual average in 2018-2020	Based data from
36 kV overhead line bare of E.ON, (Friledning, oisolerad)	0,17384	0,17101	0,33	1,72	99,99934%	99,99664%	E.ON Energidistribution AB

4.6 RECOMMENTED STATISTICS FOR OVERHEAD LINES

Based on the reliability statistics obtained above, the recommended reliability data for overhead lines are summarized in table 4.6.1 below.

28 Table 4.6.1: Recommended reliability data for 36-400 kV overhead lines

Equipment	Failure rate, 10-year annual average in 2012-2021 (f/yr.km),	Outage time, 4-year average in 2018-2021 (h/f)	Availability, 4-year annual average in 2018-2021	Based data from	Remarks
400 kV overhead line (all types)	0,00340	4,14	99,99984%	SvK	For faults with outage duration > 0 (including temporary and short duration faults)
220 kV overhead line (all types)	0,00730	3,48	99,99971%		
130 kV overhead line (all types)	0,01420	1,76	99,99972%		
Equipment	Failure rate, 8-year annual average in 2014-2021 (f/yr.km)	Outage time, 8-year average in 2014-2021 (h/f)	Availability, 8-year annual average in 2014-2021	Based data from	Remarks
130 kV overhead line bare (Friledning, oisolerad)	0,00184	4,93	99,99990%	All Swedish DSOs	For sustainable permanent outages
Equipment	Failure rate, 3-year annual average in 2019-2021 (f/yr.km)	Outage time, 8-year average in 2014-2021 (h/f)	Availability, 3-year annual average in 2014-2021	Based data from	Remarks
66 kV overhead line bare (Friledning, oisolerad)	0,00355	4,78	99,99981%	All Swedish DSOs	For faults with outage duration > 0
Equipment	Failure rate, 6-year annual average in 2014-2021 (f/yr.km)	Outage time, 8-year average in 2014-2021 (h/f)	Availability, 6-year annual average in 2014-2021	Based data from	Remarks
45 kV overhead line bare (Friledning, oisolerad)	0,00570	4,09	99,99973%	All Swedish DSOs	For faults with outage duration > 0

Equipment	Failure rate, 3-year annual average in 2017-2021 (f/yr.km)	Outage time, 8-year average in 2014-2021 (h/f)	Availability, 3-year annual average in 2017-2021	Based data from	Remarks
36 kV overhead line bare (Friledning, oisolerad)	0,01728	3,54	99,99930%	All Swedish DSOs	For faults with outage duration > 0

5 Reliability Data of Power Cables

5.1 220–400 KV UNDERGROUND CABLES

The data related to fault occurrences and the length of underground cables on 200-400 kV are presented in the tables below based on SvK's report to ENTSO-E [1] . Table 5.1.1 presents the length of the cables and the number of faults. Table 5.1.2 presents outage durations of the faults, and table 5.1.3 the reliability data calculated for the 220-400 kV underground cables.

Some additional observations on the reliability statistics of 220-400 kV underground cables are as follows:

- The outage durations appear to experience a large variation. For 220 kV cables the outage time varies from 0,02 to 714,83 (h/f), while the outage time for 400 kV cables from 0.0 to 453,21 (h/f) during 2018-2021. The outage times are not stable since they are based small number of faults occurred during the period.
- The large variation in the outage time results in large variation in the reliability data deduced for the cables. The availability for 400 kV cables, for example, varies from 99,85773% of 3-year annual average to 100% in 2021.

29 Table 5.1.1: Length of 220-400 kV underground cables and number of failures

Equipment	Number of km in 2021	Number of failures, in 2021	Number of failures, 10-year annual average in 2012-2021	Based data from
220 kV underground cable	127,00	2	1,5	SvK
400 kV underground cable	27,50	0	0,4	SvK

30 Table 5.1.2: Outage duration of 220-400 kV underground cables

Equipment	Year	Number of failures recorded with outage time	Total outage time (h)	Outage time (h/f)	Based data from
220 kV underground cable	2018	1	714,83	714,83	SvK
	2019				
	2020	1	0	0,00	
	2021	2	0,03	0,02	
400 kV underground cable	2018	3	1359,63	453,21	
	2019				
	2020	0	0	0,00	
	2021	0	0	0,00	

31 Table 5.1.3: Reliability data of 220-400 kV underground cables

Equipment	Failure rate in 2021 (f/yr.km)	Failure rate, 10-year annual average in 2012-2021 (f/yr.km),	Outage time in 2021 (h/f)	Outage time, 3-year average in 2018-2021 (h/f)	Availability in 2021	Availability, 3-year annual average in 2018-2021	Based data from
220 kV underground cable	0,01575	0,01170	0,02	178,72	99,999997%	99,97613%	SvK
400 kV underground cable	0,00000	0,02750	0,00	453,21	100,00000%	99,85773%	SvK

5.2 130 KV UNDERGROUND CABLES

This section documents the reliability statistics for 130 kV underground cables. The fault records are obtained from two data sources: the disturbances reported by SvK, and the outage reports submitted by all Swedish DSOs. The total number of faults reported by the DSOs was much greater than that reported by SvK. The number of years covered by SvK statistics was less than that covered by the DSO statistics.

5.2.1 SvK statistics

The SvK statistics are presented in three tables below:

Table 5.2.1 shows the length of cables and the number of faults in 2021, and the 10-year annual average of the number of faults in 2012–2021. Table 5.2.2 presents the outage durations, and table 5.2.3 shows the reliability data deduced for 130 kV underground cables.

32 Table 5.2.1: Length of 130 kV underground cables and number of failures

Equipment	Number of km in 2021	Number of failures in 2021	Number of failures, 10-year annual average in 2012-2021	Based data from
130 kV underground cable	504,00	3	2,5	SvK

33 Table 5.2.2: Outage duration of 130 kV underground cables

Equipment	Year	Number of failures recorded with outage time	Total outage time (h)	Outage time (h/f)	Based data from
130 kV underground cable	2018	0	0	0,00	SvK
	2019				
	2020	1	2,83	2,83	
	2021	3	2,01	0,67	

34 Table 5.2.3: Reliability data of 130 kV power cables

Equipment	Failure rate in 2021 (f/yr.km)	Failure rate, 10-year annual average in 2012-2021 (f/yr.km),	Outage time in 2021 (h/f)	Outage time, 3-year average in 2018-2021 (h/f)	Availability in 2021	Availability, 3-year annual average in 2018-2021	Based data from
130 kV underground cable	0,00595	0,00570	0,67	1,21	99,999954%	99,99992%	SvK

5.2.2 All Swedish DSO statistics

In fault reports submitted by the Swedish DSOs, power cables are classified to three subcategories:

- underground cable, (kabel i mark)
- under water cable, (kabel i vatten)
- power cable above ground and aerial, (friledning isolerad).

Unfortunately no complete data are available for length of the power cables above ground and aerial. There are almost no fault occurrences reported for 130 kV under water cables. The reliability data could only be deduced for 130 kV underground cables.

On power company level, the data are almost missing for 130 kV cables . For Vattenfall Distribution Sweden there are no faults reported for power cables above ground and aerial, nor for under water cables. For underground cables, the number of the length are only available in four years of 2018-2021, while no faults reported for the period. There are thus no reliability data derived for the company.

For E.ON Energidistribution AB, the data are either missing or uncomplete. There are only two faults reported on 130 kV underground cables during 2014-2021, the number is too small to produce the statistics. Therefore no reliability data for 130 power cables could be produced for E.ON Energidistribution AB.

The reliability for 130 underground cables all Swedish DSO wide are shown in the tables below. Table 5.2.4 summarizes the failure rate and outage time, and table 5.2.5 the reliability data deduced.

35 Table 5.2.4 Failure rate and outage time of 130 kV underground cables

Equipment	Year	Number of km	Number of failures with outage duration > 0	Total outage time (h)	Failure rate (f/yr.km)	Outage time (h/f)	Based data from
130 kV underground cable (kabel i mark)	2014	455,97	1	0,25		0,25	All Swedish DSOs
	2015		9	130,10		14,46	
	2016		4	24,13		6,03	
	2017		6	14,43		2,41	
	2018	687,61	5	6,52	0,00727	1,30	
	2019		10	388,70		38,87	
	2020	691,48	3	1,28	0,00434	0,43	
	2021	879,93	1	0,80	0,00114	0,80	

36 Table 5.2.5: Reliability data of 130 kV underground cables

Equipment	Failure rate in 2021 (f/yr.km)	Failure rate, 8-year average in 2014-2021 (f/yr.km)	Outage time in 2021 (h/f)	Outage time, 8-year average in 2014-2021 (h/f)	Availability in 2021	Availability, 8-year average in 2014-2021	Based data from
130 kV underground cable (kabel i mark)	0,00114	0,00718	0,80	14,52	99,99999%	99,99881%	All Swedish DSOs

5.3 66 KV POWER CABLES

This section presents reliability statistics of 66 kV underground cables for both all Swedish DSOs and for Vattenfall Distribution Sweden. Due to poor data for other categories of 66 kV power cables, the reliability data for under water cables could not be obtained. No reliability data for E.ON Energidistribution AB could be produced, since no good fault data available from the company.

5.3.1 All Swedish DSO statistics

37 Table 5.3.1: Failure rate and outage time of 66 kV underground cables

Equipment	Year	Number of km	Number of failures with outage duration > 0	Total outage time (h)	Failure rate (f/yr.km)	Outage time (h/f)	Based data from
66 kV underground cable (kabel i mark)	2014		1	1,68		1,68	All Swedish DSOs
	2015		0	0,00		0,00	
	2016		3	1,23		0,41	
	2017		4	11,92		2,98	
	2018	362,71	2	1,78	0,00551	0,89	
	2019	355,74	5	3,62	0,01406	0,72	
	2020	346,49	6	6,67	0,01732	1,11	
	2021	334,13	4	43,97	0,01197	10,99	

38 Table 5.3.2: Reliability data of 66 kV underground cables

Equipment	Failure rate in 2021 (f/yr.km)	Failure rate, 8-year average in 2018-2021 (f/yr.km)	Outage time in 2021 (h/f)	Outage time, 8-year average in 2014-2021 (h/f)	Availability in 2021	Availability, 8-year average in 2018-2021	Based data from
66 kV underground cable (kabel i mark)	0,01197	0,00893	10,99	2,83	99,99850%	99,99971%	All Swedish DSOs

5.3.2 Vattenfall statistics

39 Table 5.3.3: Failure rate and outage time of 66 kV underground cables of Vattenfall

Equipment	Year	Number of km	Number of failures with outage duration > 0	Total outage time (h)	Failure rate (f/yr.km)	Outage time (h/f)	Based data from
66 kV underground cable of Vattenfall (kabel i mark)	2014		0	0,00		0,00	Vattenfall
	2015		0	0,00		0,00	
	2016		1	0,50		0,50	
	2017		2	5,68		2,84	
	2018	224,10	2	1,78	0,00892	0,89	
	2019	224,10	3	1,75	0,01339	0,58	
	2020	224,10	2	1,27	0,00892	0,64	
	2021	276,50	2	43,27	0,00723	21,64	

40 Table 5.3.4: Reliability data of 66 kV underground cables of Vattenfall

Equipment	Failure rate in 2021 (f/yr.km)	Failure rate, 8-year average in 2018-2021 (f/yr.km)	Outage time in 2021 (h/f)	Outage time, 8-year average in 2014-2021 (h/f)	Availability in 2021	Availability, 8-year average in 2018-2021	Based data from
66 kV underground cable of Vattenfall (kabel i mark)	0,00723	0,00632	21,64	4,52	99,99821%	99,99967%	Vattenfall

5.4 45 KV POWER CABLES

This section presents fault statistics for 45 kV power cables, containing reliability data all Swedish DSOs wide and for power companies including Vattenfall Distribution Sweden and E.ON Energidistribution AB.

5.4.1 All Swedish DSO statistics

The tables below in this subsection summarize the fault statistics all Swedish DSOs wide.

Table 5.4.1 shows failure rate and outage time of 45 kV underground cables, and table 5.4.2 shows reliability data of 45 kV underground cables.

Table 5.4.3 presents failure rate and outage time of 45 kV power cables above ground and aerial, and table 5.4.4 presents reliability data of 45 kV power cables above ground and aerial.

The fault statistics could not be obtained for 45 kV under water cables due to uncomplete data of the cable length (there are number of the length for two years only).

41 Table 5.4.1: Failure rate and outage time of 45 kV underground cables

Equipment	Year	Number of km	Number of failures with outage duration > 0	Total outage time (h)	Failure rate (f/yr.km)	Outage time (h/f)	Based data from
45 kV underground cable (kabel i mark)	2014	412,46	6	105,78	0,01455	17,63	All Swedish DSOs
	2015		3	99,97		0,00	
	2016		1	1,42		1,42	
	2017	426,67	4	10,35	0,00937	2,59	
	2018	499,67	2	41,42	0,00400	20,71	
	2019	494,30	7	178,82	0,01416	25,55	
	2020		3	8,12		2,71	
	2021	529,77	0	0,00	0,00000	0,00	

42 Table 5.4.2: Reliability data of 45 kV underground cables

Equipment	Failure rate in 2019 (f/yr.km)	Failure rate, 8-year average in 2014-2021 (f/yr.km)	Outage time in 2019 (h/f)	Outage time, 8-year average in 2014-2021 (h/f)	Availability in 2019	Availability, 8-year annual average in 2014-2021	Based data from
45 kV underground cable (kabel i mark)	0,01416	0,00688	25,55	17,15	99,99587%	99,99865%	All Swedish DSOs

43 Table 5.4.3: Failure rate and outage time of 45 kV power cables above ground and aerial

Equipment	Year	Number of km	Number of failures with outage duration > 0	Total outage time (h)	Failure rate (f/yr.km)	Outage time (h/f)	Based data from
45 kV power cable above ground and aerial, (friledning isolerad)	2014		4	0,433		0,11	All Swedish DSOs
	2015		2	1,683		0,84	
	2016		9	14,317		1,59	
	2017	84,33	3	1,183	0,03557	0,39	
	2018	88,78	2	0,133	0,02253	0,07	
	2019	80,73	0	0	0,00000	0,00	
	2020		0	0	0,00000	0,00	
	2021	108,11	3	8,37	0,02775	2,79	

44 Table 5.4.4: Reliability data of 45 kV power cables above ground and aerial

Equipment	Failure rate in 2021 (f/yr.km)	Failure rate, 8-year average in 2017-2021 (f/yr.km)	Outage time in 2021 (h/f)	Outage time, 8-year average in 2014-2021 (h/f)	Availability in 2021	Availability, 8-year average in 2017-2021	Based data from
45 kV power cable above ground and aerial (friledning isolerad)	0,02775	0,03177	2,79	1,14	99,99912%	99,99959%	All Swedish DSOs

5.4.2 Vattenfall statistics

At 45 kV voltage level, Vattenfall statistics are obtained for underground cables, which are summarized in the tables below. Table 5.4.5 presents failure rate and outage time and table 5.4.6 the deduced reliability data.

Due to that the equipment data are unavailable for under water cables, there are no reliability data deduced for 45 kV under water cables of the company. For power cables above ground and aerial there are only very few failures reported during 2014-2021, the number of the failures are too small to generating the statistics.

45 Table 5.4.5: Failure rate and outage time of 45 kV underground cables of Vattenfall

Equipment	Year	Number of km	Number of failures with outage duration > 0	Total outage time (h)	Failure rate (f/yr.km)	Outage time (h/f)	Based data from
45 kV underground cable of Vattenfall (kabel i mark)	2014	108,46	1	0,70	0,00922	0,70	Vattenfall
	2015		0	0,00	0,00000	0,00	
	2016		0	0,00	0,00000	0,00	
	2017	124,66	1	2,97	0,00802	2,97	
	2018	165,62	1	2,53	0,00604	2,53	
	2019	169,80	3	139,28	0,01767	46,43	
	2020	169,80	1	0,10	0,00589	0,10	
	2021	174,60	0	0,00	0,00000	0,00	

46 Table 5.4.6: Reliability data of 45 kV underground cables of Vattenfall

Equipment	Failure rate in 2020 (f/yr.km)	Failure rate, 8-year average in 2014-2021 (f/yr.km)	Outage time in 2020 (h/f)	Outage time, 8-year average in 2014-2021 (h/f)	Availability in 2020	Availability, 8-year average in 2014-2021	Based data from
45 kV underground cable of Vattenfall (kabel i mark)	0,00589	0,00575	0,10	20,80	99,99999%	99,99863%	Vattenfall

5.4.3 E.ON Energidistribution AB statistics

The tables below in this section summarize reliability statistics for 45 kV underground cables and power cable above ground and aerial of E.ON Energidistribution AB.

For 45 kV under water cables, no reliability data are deduced due to uncomplete equipment data as well as too small number of faults reported on 45 kV under water cables of the company.

47 Table 5.4.7: Failure rate and outage time of 45 kV underground cables of E.ON Energidistribution AB

Equipment	Year	Number of km	Number of failures with outage duration > 0	Total outage time (h)	Failure rate (f/yr.km)	Outage time (h/f)	Based data from
45 kV underground cable of E.ON (kabel i mark)	2014	81,63	1	0,37	0,01225	0,37	E.ON Energidistribution AB
	2015		0	0,00		0,00	
	2016		0	0,00		0,00	
	2017	99,76	1	3,18	0,01002	3,18	
	2018	102,62	1	38,88	0,00974	38,88	
	2019		1	31,58		31,58	
	2020	132,03	0	0,00		0,00	
	2021	145,31	0	0,00		0,00	

48 Table 5.4.8: Reliability data of 45 kV underground cables of E.ON Energidistribution AB

Equipment	Failure rate in 2018 (f/yr.km)	Failure rate, 8-year average in 2014-2021 (f/yr.km)	Outage time in 2018 (h/f)	Outage time, 8-year average in 2014-2021 (h/f)	Availability in 2018	Availability, 8-year average in 2014-2021	Based data from
45 kV underground cable of E.ON (kabel i mark)	0,00974	0,00445	38,88	18,50	99,99567%	99,99906%	E.ON Energidistribution AB

49 Table 5.4.9: Failure rate and outage time of 45 kV power cables above ground and aerial of E.ON Energidistribution AB

Equipment	Year	Number of km	Number of failures with outage duration > 0	Total outage time (h)	Failure rate (f/yr.km)	Outage time (h/f)	Based data from
45 kV power cable above ground and aerial, of E.ON (friledning isolerad)	2014	3,29	2	0,35	0,60790	0,18	E.ON Energidistribution AB
	2015		1	1,67		1,67	
	2016		4	13,17		3,29	
	2017	3,29	1	1,07	0,30395	1,07	
	2018	3,29	0	0,00	0,00000	0,00	
	2019	3,29	0	0,00	0,00000	0,00	
	2020	3,29	0	0,00	0,00000	0,00	
	2021	3,29	0	0,00	0,00000	0,00	

50 Table 5.4.10: Reliability data of 45 kV power cables above ground and aerial of E.ON Energidistribution AB

Equipment	Failure rate in 2017 (f/yr. km)	Failure rate, 8-year average in 2014-2021 (f/yr.km)	Outage time in 2017 (h/f)	Outage time, 8-year average in 2014-2021 (h/f)	Availability in 2017	Availability, 8-year average in 2014-2021	Based data from
45 kV power cable above ground and aerial of E.ON (friledning isolerad)	0,30395	0,30395	1,07	2,03	99,99629%	99,99295%	E.ON Energidistribution AB

5.5 36 KV POWER CABLES

This section summarizes reliability statistics for all three types of 36 kV power cables all Swedish DSOs wide.

At power company level the fault statistics can be obtained for underground cables as well as for under water cables of E:ON Energidistribution AB. No equipment data available for power cables above ground and aerial, thus no reliability data are produced for this kind of cables of the company.

No any reliability data of power cables could be generated for Vattenfall Distribution Sweden on 36 kV voltage level, since there are no equipment data available for power cables above ground and aerial, nor for under water cables, and no faults reported on underground cables during 2014-2021.

5.5.1 All Swedish DSO statistics

Table 5.5.1 presents failure rate and outage time of 36 kV underground cables, and table 5.5.2 reliability data of 36 kV underground cables.

Table 5.5.3 presents failure rate and outage time of 36 kV power cables above ground and aerial, and table 5.5.4 reliability data of 36 kV power cables above ground and aerial.

Table 5.5.5 presents failure rate and outage time of 36 kV under water cables, and table 5.5.6 reliability data of 36 kV under water cables.

51 Table 5.5.1: Failure rate and outage time of 36 kV underground cables

Equipment	Year	Number of km	Number of failures with outage duration > 0	Total outage time (h)	Failure rate (f/yr.km)	Outage time (h/f)	Based data from
36 kV underground cable (kabel i mark)	2014	840,48	3	187,85	0,00357	62,62	All Swedish DSOs
	2015		8	183,82		0,00	
	2016		7	123,35		17,62	
	2017		9	350,87		38,99	
	2018		8	94,32		11,79	
	2019		13	91,03		7,00	
	2020		11	623,07		56,64	
	2021	752,51	3	2,28	0,00399	0,00	

52 Table 5.5.2: Reliability data of 36 kV underground cables

Equipment	Failure rate in 2021 (f/yr.km)	Failure rate, 8-year average in 2014-2021 (f/yr.km)	Outage time in 2021 (h/f)	Outage time, 8-year average in 2014-2021 (h/f)	Availability in 2021	Availability, 8-year average in 2014-2021	Based data from
36 kV underground cable (kabel i mark)	0,00399	0,00973	7,00	26,72	99,99968%	99,99703%	All Swedish DSOs

53 Table 5.5.3: Failure rate and outage time of 36 kV power cables above ground and aerial

Equipment	Year	Number of km	Number of failures with outage duration > 0	Total outage time (h)	Failure rate (f/yr.km)	Outage time (h/f)	Based data from
36 kV power cable above ground and aerial, (friledning isolerad)	2014		3	35,38		11,79	All Swedish DSOs
	2015		0	0,00		0,00	
	2016		5	12,23		2,45	
	2017		3	0,65		0,22	
	2018	12,87	0	0,00	0,00000	0,00	
	2019		0	0,00		0,00	
	2020		5	68,18		13,64	
	2021	12,89	2	9,47	0,15516	4,74	

54 Table 5.5.4: Reliability data of 36 kV power cables above ground and aerial

Equipment	Failure rate in 2021 (f/yr.km)	Failure rate, 8-year average in 2014-2021 (f/yr.km)	Outage time in 2021 (h/f)	Outage time, 8-year average in 2014-2021 (h/f)	Availability in 2017	Availability, 8-year average in 2014-2021	Based data from
36 kV power cable above ground and aerial (friledning isolerad)	0,15516	0,17469	4,74	7,00	99,99161%	99,98605%	All Swedish DSOs

55 Table 5.5.5: Failure rate and outage time of 36 kV under water cables

Equipment	Year	Number of km	Number of failures with outage duration > 0	Total outage time (h)	Failure rate (f/yr.km)	Outage time (h/f)	Based data from
36 kV under water cable (kabel i vatten)	2014	19,12	1	1,20	0,05230	1,20	All Swedish DSOs
	2015		0	0,00		0,00	
	2016		2	182,42		91,21	
	2017	19,12	0	0,00	0,00000	0,00	
	2018	19,10	0	0,00	0,00000	0,00	
	2019	19,10	0	0,00	0,00000	0,00	
	2020	19,10	0	0,00	0,00000	0,00	
	2021	19,10	0	0,00	0,00000	0,00	

56 Table 5.5.6: Reliability data of 36 kV under water cables

Equipment	Failure rate in 2014 (f/yr.km)	Failure rate, 8-year average in 2014-2021 (f/yr.km)	Outage time in 2014 (h/f)	Outage time, 8-year average in 2014-2021 (h/f)	Availability in 2014	Availability, 8-year average in 2014-2021	Based data from
36 kV under water cable (kabel i vatten)	0,05230	0,01963	1,20	61,21	99,99928%	99,98629%	All Swedish DSOs

5.5.2 E.ON Energidistribution AB statistics

Table 5.5.7 shows failure rate and outage time of 36 kV underground cables, and table 5.5.8 reliability data of 36 kV underground cables of E.ON Energidistribution AB.

Table 5.5.9 shows failure rate and outage time of 36 kV under water cables, and table 5.5.10 reliability data of 36 kV under water cables of E.ON Energidistribution AB.

57 Table 5.5.7: Failure rate and outage time of 36 kV underground cables of E.ON Energidistribution AB

Equipment	Year	Number of km	Number of failures with outage duration > 0	Total outage time (h)	Failure rate (f/yr.km)	Outage time (h/f)	Based data from
36 kV underground cable of E.ON (kabel i mark)	2014	270,55	3	187,85	0,01109	62,62	E.ON Energidistribution AB
	2015		5	177,32		35,46	
	2016		5	120,90		24,18	
	2017	294,17	5	336,55	0,01700	67,31	
	2018	294,20	4	93,32	0,01360	23,33	
	2019	294,62	6	80,07	0,02037	13,35	
	2020	295,29	0	0,00	0,00000	0,00	
	2021	296,60	0	0,00	0,00000	0,00	

58 Table 5.5.8: Reliability data of 36 kV underground cables of E.ON Energidistribution AB

Equipment	Failure rate in 2019 (f/yr.km)	Failure rate, 8-year average in 2014-2021 (f/yr.km)	Outage time in 2019 (h/f)	Outage time, 8-year average in 2014-2021 (h/f)	Availability in 2019	Availability, 8-year average in 2014-2021	Based data from
36 kV underground cable of E.ON (kabel i mark)	0,02037	0,01203	13,35	35,57	99,99690%	99,99511%	E.ON Energidistribution AB

59 Table 5.5.9: Failure rate and outage time of 36 kV under water cables of E.ON Energidistribution AB

Equipment	Year	Number of km	Number of failures with outage duration > 0	Total outage time (h)	Failure rate (f/yr.km)	Outage time (h/f)	Based data from
36 kV under water cable of E.ON (kabel i vatten)	2014	19,12	1	1,60	0,05230	1,60	E.ON Energidistribution AB
	2015		0	0,00			
	2016		2	182,42		91,21	
	2017	19,10	0	0,00	0,00000		
	2018	19,10	0	0,00	0,00000		
	2019	19,10	1	6,22	0,05236	6,22	
	2020	19,10	0	0,00	0,00000		
	2021	19,10	0	0,00	0,00000		

60 Table 5.5.10: Reliability data of 36 kV under water cables of E.ON Energidistribution AB

Equipment	Failure rate in 2019 (f/yr.km)	Failure rate, 8-year average in 2014-2021 (f/yr.km)	Outage time in 2019 (h/f)	Outage time, 8-year average in 2014-2021 (h/f)	Availability in 2019	Availability, 8-year average in 2014-2021	Based data from
36 kV under water cable (kabel i vatten)	0,05236	0,02617	6,22	47,56	99,99628%	99,98579%	E.ON Energidistribution AB

5.6 RECOMMENTED STATISTICS FOR POWER CABLES

Based on the study of the statistics listed above, the recommended reliability data for power cables are summarized below:

61 Table 5.6.1: Recommended failure rate of 220-400 kV underground cables

Equipment	Failure rate, 10-year annual average in 2012-2021 (f/yr.km)	Based data from
400 kV underground cable	0,02750	SvK
220 kV underground cable	0,01710	SvK

62 Table 5.6.2: Recommended reliability data for 36-130 kV power cables

Equipment	Failure rate, 8-year average in 2014-2021 (f/yr.km)	Outage time, 8-year average in 2014-2021 (h/f)	Availability, 8-year average in 2014-2021	Based data from
130 kV underground cable (kabel i mark)	0,00718	14,52	99,99881%	All Swedish DSOs
66 kV underground cable (kabel i mark)	0,00893	2,83	99,99971%	
45 kV underground cable (kabel i mark)	0,00688	17,15	99,99865%	
45 kV power cable above ground and aerial (friledning isolerad)	0,03177	1,14	99,99959%	
36 kV underground cable (kabel i mark)	0,00973	26,72	99,99703%	
36 kV power cable above ground and aerial (friledning isolerad)	0,17469	7,00	99,98605%	
36 kV under water cable (kabel i vatten)	0,01963	61,21	99,98629%	

6 Reliability Data of Power Transformers

This chapter presents reliability data of power transformers, that are produced based on the statistics published by the ENTSO-E and the fault records collected by SvK during 2018-2021.

The outage data for power transformers submitted to Energiföretagen by Swedish DSOs during 2014-2021 are not good, only few faults in two years are reported (two faults on 45 kV transformers in 2014 and in 2016 respectively, and two faults on 130 kV transformers in 2016). The reliability data for power transformers could not be therefore produced based on the faults data from Swedish DSOs.

Vattenfall Distribution Sweden records and documents the transformer outages together with the associated details. The company has well recorded transformer failures and related information, such as rating, voltage and outage duration from the year 2006. The 14-year annual average reliability statistics in the period of 2006-2019 are generated based on the outage records of Vattenfall, which are also summarized in this chapter.

6.1 SVK STATISTICS

This section presents power transformer faults in 2012–2021 based on the ENTSO-E report [1]. The rated voltage of a power transformer is defined in these statistics as the winding with the highest voltage.

Table 6.1.1 presents the number of power transformers, the number of faults in 2021, and the 10-year annual average of the number of faults in 2012–2021. Table 6.1.2 presents the outage duration of the 100-400 kV power transformers. Table 6.1.3 shows reliability data of the 100-400 kV power transformers.

63 Table 6.1.1 Number of 100-400 kV power transformers and failures

Equipment	Number of units in 2021	Number of failures in 2021	Number of failures, 10-year annual average in 2012-2021	Based data from
100-150 kV power transformer	881,00	9,00	18,40	SvK
220-330 kV power transformer	116,00	0	3,2	
380-420 kV power transformer	86,00	0	1,5	

64 Table 6.1.2: Outage duration of 100-400 kV power transformers

Equipment	Year	Number of failures recorded with outage time	Total outage time (h)	Outage time (h/f)	Based data from
100-150 kV power transformer	2018	5	4,57	0,91	SvK
	2019	3	0,48	0,16	
	2020	2	0,48	0,24	
	2021	8	169,68	21,21	
220-330 kV power transformer	2018	1	15,55	15,55	
	2019	0	0,00	0,00	
	2020	1	0,07	0,07	
	2021	0	0,00	0,00	
380-420 kV power transformer	2018	0	0,00	0,00	
	2019	0	0,00	0,00	
	2020	0	0,00	0,00	
	2021	0	0,00	0,00	

65 Table 6.1.3: Reliability data of 100-400 kV power transformers

Equipment	Failure rate in 2021 (f/yr.unit)	Failure rate, 10-year annual average in 2012-2021 (f/yr.unit),	Outage time in 2021 (h/f)	Outage time, 4-year average in 2018-2021 (h/f)	Availability in 2021	Availability, 4-year average in 2018-2021	Based data from
100-150 kV power transformer	0,01022	0,02320	21,21	9,73	99,997527%	99,99742%	SvK
220-330 kV power transformer	0,00000	0,03040	0,00	7,81	100,00000%	99,99729%	
380-420 kV power transformer	0,00000	0,02090	0,00	0,00	100,00000%	100,00000%	

6.2 VATTENFALL STATISTICS

The outage data of Vattenfall Distribution Sweden are divided into two groups depending on voltages, namely, a group of 30-70 kV sub-transmission level and a group of 130-400 kV transmission level. The reliability data are then calculated

separately for each group. The detailed reliability data deduced are presented in the tables below.

6.2.1 130-400 kV power transformers

Table 6.2.1 shows the number of 130-400 kV power transformers and number of the failures of Vattenfall Distribution Sweden in 2006-2019.

Table 6.2.2 lists the outage duration of 130-400 kV power transformers, and table 6.2.3 reliability data of 130-400 kV power transformers of Vattenfall Distribution Sweden.

66 Table 6.2.1: Number of 130-400 kV power transformer and number of failures

Equipment	Number of transformers in 2018	Number of failures in 2018	Number of failures, 14-year annual average in 2006-2019	Based data from
130-400 kV power transformer of Vattenfall	526	2	3,13	Vattenfall

67 Table 6.2.2: Outage duration of 130-400 kV power transformer of Vattenfall

Equipment	Year	Number of failures recorded with outage time	Total outage time (h)	Outage time (h/f)	Based data from
130-400 kV power transformer of Vattenfall	2006	0	0,00	0,00	Vattenfall
	2007	0	0,00	0,00	
	2008	0	0,00	0,00	
	2009	6	24,58	4,10	
	2010	6	5,00	0,83	
	2011	9	4,80	0,53	
	2012	6	3,65	0,61	
	2013	2	6,12	3,06	
	2014	1	0,17	0,17	
	2015	2	148,20	74,10	
	2016	4	90,77	22,69	
	2017	2	48,35	24,18	
	2018	2	69,50	34,75	
	Jan.-May 2019	2	4,68	2,34	

68 Table 6.2.3: Reliability data of 130-400 kV power transformers

Equipment	Failure rate in 2018 (f/yr.unit)	Failure rate, 14-year average in 2006-2019 (f/yr.unit),	Outage time in 2018 (h/f)	Outage time, 14-year average in 2006-2019 (h/f)	Availability in 2018	Availability, 14-year annual average in 2006-2019	Based data from
130-400 kV power transformer of Vattenfall	0,00380	0,00566	34,75	9,66	99,99849%	99,99938%	Vattenfall

6.2.2 30-70 kV power transformer

Table 6.2.4 shows the outage duration of 30-70 kV power transformers, and the table 6.2.5 presents the number of 30-70 kV power transformers and number of the failures of Vattenfall Distribution Sweden in 2006-2019.

Table 6.2.6 shoes the reliability data of 30-70 kV power transformers of Vattenfall Distribution Sweden.

69 Table 6.2.4: Outage duration of 30-70 kV power transformer of Vattenfall

Eqipment	Year	Number of failures recorded with outage time	Total outage time (h)	Outage time (h/f)	Based data from
30-70 kV power transformer of Vattenfall	2006	0	0,00	0,00	Vattenfall
	2007	2	2,12	1,06	
	2008	2	2,35	1,18	
	2009	5	19,13	3,83	
	2010	6	7,58	1,26	
	2011	3	0,57	0,19	
	2012	7	9,07	1,30	
	2013	4	35,48	8,87	
	2014	7	112,65	16,09	
	2015	10	134,17	13,42	
	2016	5	8,73	1,75	
	2017	2	2,67	1,33	
	2018	3	10,23	3,41	
	Jan.-May 2019	1	4,50	4,50	

70 Table 6.2.5: Number of 30-70 kV power transformers and number of failures

Equipment	Number of transformers in 2018	Number of failures in 2018	Number of failures, 14-year annual average in 2006-2019	Based data from
30-70 kV power transformer of Vattenfall	746	3	4,248	Vattenfall

71 Table 6.2.6: Reliability data of 30-70 kV power transformer

Equipment	Failure rate in 2018 (f/yr.unit)	Failure rate, 14-year average in 2006-2019 (f/yr.unit),	Outage time in 2018 (h/f)	Outage time, 14-year average in 2006-2019 (h/f)	Availability in 2018	Availability, 14-year annual average in 2006-2018	Based data from
30-70 kV power transformer of Vattenfall	0,00402	0,00542	3,41	6,13	99,99984%	99,99962%	Vattenfall

6.3 RECOMMENTED STATISTICS FOR POWER TRANSFORMERS

Based on the analysis of the statistics documented above, the recommended reliability data for power transformers are summarized below:

72 Table 6.3.1: Recommended reliability data for 30-400 kV power transformer

Equipment	Failure rate, 10-year annual average in 2012-2021 (f/yr.unit)	Outage time, 4-year average in 2018-2021 (h/f)	Availability, 4-year average in 2018-2021	Based data from
100-150 kV power transformer	0,02320	9,73	99,99742%	SvK
220-330 kV power transformer	0,03040	7,81	99,99729%	
Equipment	Failure rate, 14-year average in 2006-2019 (f/yr.unit),	Outage time, 14-year average in 2006-2019 (h/f)	Availability, 14-year annual average in 2006-2019	Based data from
30-70 kV power transformer	0,00542	6,13	99,99962%	Vattenfall
130-400 kV power transformer	0,00566	9,66	99,99938%	

7 Reliability Data of Circuit Breakers

This chapter presents reliability data of circuit breakers. These statistics are obtained based on the grid disturbance statistics published by the ENTSO-E and the outage records collected by SvK during 2018-2021 [1]. Due to that the equipment population data for circuit breakers reported to Energiföretagen by Swedish DSOs are not complete, no reliability data could be generated based on data from Swedish DSOs.

7.1 SVK STATISTICS

Table 7.1.1 presents the number of circuit breakers, the number of faults in 2021, and the 10-year annual average of the number of faults for the period of 2012–2021. Table 7.1.2 presents outage duration of 100-420 kV circuit breakers. Table 7.1.3 presents reliability data of 100-420 kV circuit breakers.

73 Table 7.1.1 Number of 100-420 kV circuit breakers and failures

Equipment	Number of units in 2021	Number of failures in 2021	Number of failures, 10-year annual average in 2012-2021	Based data from
100-150 kV circuit breaker	2835	5	4,1	SvK
220-330 kV circuit breaker	362	2	1,3	
380-420 kV circuit breaker	714	4	4,9	

74 Table 7.1.2: Outage duration of 100-420 kV circuit breakers

Equipment	Year	Number of failures recorded with outage time	Total outage time (h)	Outage time (h/f)	Based data from
100-150 kV circuit breaker	2018	1	0,62	0,62	SvK
	2019	2	18,05	9,03	
	2020	0	0,00	0,00	
	2021	4	49,99	12,50	
220-330 kV circuit breaker	2018	2	155,37	77,68	
	2019	0	0,00	0,00	
	2020	2	2,32	1,16	
	2021	2	2,32	1,16	
380-420 kV circuit breaker	2018	3	36,62	12,21	
	2019	4	2,37	0,59	
	2020	20	514,12	25,71	
	2021	4	60,87	15,22	

75 Table 7.1.3: Reliability data of 100-420 kV circuit breakers

Equipment	Failure rate in 2021 (f/yr.unit)	Failure rate, 10-year annual average in 2012-2021 (f/yr.unit)	Outage time in 2021 (h/f)	Outage time, 4-year average in 2018-2021 (h/f)	Availability in 2021	Availability, 4-year average in 2018-2021	Based data from
100-150 kV circuit breaker	0,00176	0,00180	12,50	9,81	99,999748%	99,99980%	SvK
220-330 kV circuit breaker	0,00552	0,00400	1,16	26,67	99,99993%	99,99878%	
380-420 kV circuit breaker	0,00560	0,00810	15,22	19,81	99,99903%	99,99817%	

7.2 RECOMMENTED STATISTICS FOR CIRCUIT BREAKER

The table below presents the recommended reliability data for circuit breakers.

76 Table 7.2.1: Recommended reliability data for 100-420 kV circuit breakers

Equipment	Failure rate, 10-year annual average in 2012-2021 (f/yr.unit),	Outage time, 4-year average in 2018-2021 (h/f)	Availability, 4-year average in 2018-2021	Based data from
100-150 kV circuit breaker	0,00180	9,81	99,99980%	SvK
220-330 kV circuit breaker	0,00400	26,67	99,99878%	
380-420 kV circuit breaker	0,00810	19,81	99,99817%	

8 Reliability Data of Control Equipment

This chapter presents reliability data of control equipment. These statistics are obtained based on the grid disturbance statistics published by the ENTSO-E and the outage records collected by SvK during 2018-2021 [1].

Due to that there are no equipment data nor fault occurrences of control equipment reported to Energiföretagen by the Swedish DSOs during 2014-2021, no reliability data therefore could be generated based on the data from the Swedish DSOs.

The control equipment considered by SvK includes the following sub-components:

- Alarm system;
- Automatics, such as synchronous and phasing device, interlocking device, sequential control, and voltage control;
- Remote control;
- Control cable;
- Installation cabinet;
- Local control;
- Grid protection, and protection device, including communication;
- Optic cable;
- Signal transmission (data communication);
- Reclosing.

It should be mentioned that protection devices are considered as a part of the control equipment here. Control equipment embedded in other components (excluded in the list above), are not included in this category since they are treated as a part of the other component, for example, fault in control equipment embedded in the circuit breaker is counted as fault of circuit breaker.

Human error is registered under operation and maintenance, separated from the category of technical equipment. Incorrect settings in control equipment or in protection devices are treated as human errors, not faults of control equipment.

8.1 SVK STATISTICS

Table 8.1.1 presents the number of control equipment and the number of faults in 2021, and the 10-year annual average of the number of faults in 2012–2021. Table 8.1.2 presents outage duration of 100-420 kV control equipment grouped by voltage levels. Table 8.1.3 summarizes reliability data of 100-420 kV control equipment.

77 Table 8.1.1 Number of 100-420 kV control equipment and failures

Equipment	Number of units in 2021	Number of failures in 2021	Number of failures, 10-year annual average in 2012-2021	Based data from
100-150 kV control equipment	2835	19	17,4	SvK
220-330 kV control equipment	362	18	12,2	
380-420 kV control equipment	714	35	25,3	

78 Table 8.1.2: Outage duration of 100-420 kV control equipment

Equipment	Year	Number of failures recorded with outage time	Total outage time (h)	Outage time (h/f)	Based data from
100-150 kV control equipment	2018	19	58,37	3,07	SvK
	2019	11	6,57	0,60	
	2020	2	0,20	0,10	
	2021	8	479,33	59,92	
220-330 kV control equipment	2018	19	36,60	1,93	
	2019	4	801,65	200,41	
	2020	4	43,80	10,95	
	2021	18	37,46	2,08	
380-420 kV control equipment	2018	15	84,37	5,62	
	2019	17	558,25	32,84	
	2020	21	118,20	5,63	
	2021	35	772,02	22,06	

79 Table 8.1.3: Reliability data of 100-420 kV control equipment

Equipment	Failure rate in 2021 (f/yr.unit)	Failure rate, 10-year annual average in 2012-2021 (f/yr.unit),	Outage time in 2021 (h/f)	Outage time, 4-year average in 2018-2021 (h/f)	Availability in 2021	Availability, 4-year average in 2018-2021	Based data from
100-150 kV control equipment	0,00670	0,00750	59,92	13,61	99,995416%	99,99883%	SvK
220-330 kV control equipment	0,04972	0,03730	2,08	20,43	99,99882%	99,99130%	
380-420 kV control equipment	0,04902	0,04160	22,06	17,42	99,98766%	99,99173%	

8.2 RECOMMENTED STATISTICS FOR CONTROL EQUIPMENT

The recommended reliability data for control equipment are summarized in the table 8.2.1 below.

80 Table 8.2.1: Recommended reliability data for 100-420 kV control equipment

Equipment	Failure rate, 10-year annual average in 2012-2021 (f/yr.unit)	Outage time, 4-year average in 2018-2021 (h/f)	Availability, 4-year average in 2018-2021	Based data from
100-150 kV control equipment	0,00750	13,61	99,99883%	SvK
220-330 kV control equipment	0,03730	20,43	99,99130%	
380-420 kV control equipment	0,04160	17,42	99,99173%	

9 Reliability Data of Instrument Transformers

An instrument transformer is a transformer used to measure electrical quantities like current, voltage, power, frequency and power factor. Instrument transformers are high accuracy electrical devices installed on AC power systems to isolate or to transform voltage or current levels. The most common instrument transformers include current transformers and voltage transformers.

Unfortunately in the outage database at Energiföretagen there are no equipment data nor fault occurrences data for instrument transformers from the Swedish DSOs during 2014-2021, therefore no reliability statistics could be generated based on data from Swedish DSOs.

The reliability statistics of instrument transformers presented in this chapter are obtained based on the grid disturbance statistics published by the ENTSO-E and the outage records collected by SvK during 2018-2021 [1, 5, 6].

9.1 SVK STATISTICS

Component instrument transformers considered by SvK in fault statistics include the following sub-components:

- Foundations and support structure;
- Isolator;
- Core;
- Winding;
- Voltage diverter;
- Breaker, if integrated in instrument transformer.

Instrument transformers are counted as individual components. One component for one-phased units and three components for three-phased units.

The tables below present instrument transformer faults in 2021 and during 2012-2021.

Table 9.1.1 presents the number of 100-420 kV instrument transformers and the number of faults in 2021, and the 10-year annual average of the number of faults in 2012–2021.

Table 9.1.2 presents outage duration of 100-420 kV instrument transformers.

Table 9.1.3 presents reliability data of 100-420 kV instrument transformers grouped by voltage levels.

81 Table 9.1.1 Number of 100-420 kV instrument transformers and failures

Equipment	Number of units in 2021	Number of failures in 2021	Number of failures, 10-year annual average in 2012-2021	Based data from
100-150 kV instrument transformer	9212	3	3,9	SvK
220-330 kV instrument transformer	1976	0	0,2	
380-420 kV instrument transformer	3741	1	1,9	

82 Table 9.1.2: Outage duration of 100-420 kV instrument transformers

Equipment	Year	Number of failures recorded with outage time	Total outage time (h)	Outage time (h/f)	Based data from
100-150 kV instrument transformer	2018	3	4,92	1,64	SvK
	2019	1	0,35	0,35	
	2020	0	0,00	0,00	
	2021	3	185,31	61,77	
220-330 kV instrument transformer	2018	0	0,00	0,00	
	2019	1	42,57	42,57	
	2020	0	0,00	0,00	
	2021	0	0,00	0,00	
380-420 kV instrument transformer	2018	0	0,00	0,00	
	2019	0	0,00	0,00	
	2020	1	5,82	5,82	
	2021	1	75,52	75,52	

83 Table 9.1.3: Reliability data of 100-420 kV instrument transformers

Equipment	Failure rate in 2021 (f/yr.unit)	Failure rate, 10-year annual average in 2012-2021 (f/yr.unit),	Outage time in 2021 (h/f)	Outage time, 4-year average in 2018-2021 (h/f)	Availability in 2021	Availability, 4-year average in 2018-2021	Based data from
100-150 kV instrument transformer	0,00033	0,00080	61,77	27,23	99,999770%	99,99975%	SvK
220-330 kV instrument transformer	0,00000	0,00020	0,00	42,57	100,00000%	99,99990%	
380-420 kV instrument transformer	0,00027	0,00090	75,52	40,67	99,99977%	99,99958%	

9.2 RECOMMENTED STATISTICS FOR INSTRUMENT TRANSFORMER

The recommended reliability data for instrument transformers are summarized in the table 9.2.1 below.

84 Table 9.2.1: Recommended reliability data for 100-420 kV instrument transformers

Equipment	Failure rate, 10-year annual average in 2012-2021 (f/yr.unit)	Outage time, 4-year average in 2018-2021 (h/f)	Availability, 4-year average in 2018-2021	Based data from
100-150 kV instrument transformer	0,00080	27,23	99,99975%	SvK
220-330 kV instrument transformer	0,00020	42,57	99,99990%	
380-420 kV instrument transformer	0,00090	40,67	99,99958%	

10 Reliability Data of Reactors

A reactor is a coil that is mainly used for protecting devices and components of a power system from the reactive currents generated during the fault conditions in the power transmission. The reactor is mainly made up of inductive material. The main purpose of using the reactor is to limit the reacting currents which may cause damage on power system components during power transmission. The reactors may have different functions according to their usage, such as elimination of harmonics and reactive currents, and fault correction.

This chapter presents the fault statistics of reactors based on the grid disturbance statistics published by the ENTSO-E and the outage records collected by SvK during 2018-2021 [1, 5, 6].

The outage database at Energiföretagen contains no equipment data nor fault occurrence data for reactors from the Swedish DSOs during 2014-2021, therefore no reliability statistics could be generated based on data from the Swedish DSOs.

10.1 SVK STATISTICS

Component reactors considered in faults statistics by SvK include the following sub-components:

- Foundations, including oil sumps;
- Bushing;
- Sensors (incl. oil level sensors), gas, temperature and pressure guards;
- Cooling, including integrated cooling automatics;
- Core;
- Windings;
- Tap changers, including control equipment;
- Instrument transformers, if integrated in reactor;
- Tank;
- Reactor switch gear.

Reactors inclusive of neutral point reactors are considered as one component per three-phased connection organ.

The voltage level of reactors is not registered in the collected data, the reliability data for reactors is therefore for one voltage group 220-420 kV only.

The following tables presents faults statistics for reactors.

Table 10.1.1 presents the number of 220-420 kV reactors and their faults in 2021.

Table 10.1.2 shows outage duration of 220-420 kV reactors during 2018-2021, and table 10.1.3 gives the reliability data deduced for 220-420 kV reactors.

85 Table 10.1.1 Number of 220-420 kV reactors and failures

Equipment	Number of units in 2021	Number of failures in 2021	Based data from
220-420 kV reactor	855	6	SvK

86 Table 10.1.2: Outage duration of 220-420 kV reactors

Equipment	Year	Number of failures recorded with outage time	Total outage time (h)	Outage time (h/f)	Based data from
220-420 kV reactor	2018	7	21,38	3,05	SvK
	2019	9	566,12	62,90	
	2020	3	18,52	6,17	
	2021	6	199,65	33,28	

87 Table 10.1.3: Reliability data of 220-420 kV reactors

Equipment	Failure rate in 2021 (f/yr.unit)	Failure rate, 10-year annual average in 2012-2021 (f/yr.unit)	Outage time in 2021 (h/f)	Outage time, 4-year average in 2018-2021 (h/f)	Availability in 2021	Availability, 4-year average in 2018-2021	Based data from
220-420 kV reactor	0,00702	0,01900	33,28	32,23	99,997334%	99,99301%	SvK

10.2 RECOMMENTED STATISTICS FOR REACTORS

The recommended reliability data for 220-420 kV reactors are summarized in the table 10.2.1 below.

88 Table 10.2.1: Recommended reliability data for 220-420 kV reactors

Equipment	Failure rate, 10-year annual average in 2012-2021 (f/yr.unit)	Outage time, 4-year average in 2018-2021 (h/f)	Availability, 4-year average in 2018-2021	Based data from
220-420 kV reactor	0,01900	32,23	99,99301%	SvK

11 Reliability Data of Series Capacitors

This chapter and the following two chapters present fault statistics for compensation devices, this chapter for series capacitors, and the following chapters for shunt capacitors and for static var compensators (SVCs).

Series capacitors are compensation devices on a power system. They are used to compensate inductance of transmission lines. Series capacitors will increase the transmission capacity and the stability of the lines.

This chapter presents the fault statistics of series capacitors based on the grid disturbance statistics published by the ENTSO-E and the outage records collected by SvK during 2018-2021 [1, 5, 6].

The outage database at Energiföretagen contains no equipment data nor fault occurrence data for series capacitors from the Swedish DSOs during 2014-2021, therefore no reliability statistics could be generated based on the data from the Swedish DSOs.

11.1 SVK STATISTICS

Component series capacitors considered by SvK in faults statistics include the following sub-components:

- Surge arresters and varistors;
- Spark gap;
- Capacitor;
- Resistor;
- Instrument transformer if integrated in series capacitor battery or filter;
- Reactor;
- Support isolator.

Series capacitors are considered as one component per three-phased connection organ.

The following tables presents fault statistics for series capacitors.

Table 11.1.1 presents the number of 380-420 kV series capacitors and number of faults in 2021.

Table 11.1.2 shows outage duration of 380-420 kV series capacitors during 2018-2021, and the table 11.1.3 gives the reliability data deduced for 380-420 kV series capacitors.

89 Table 11.1.1 Number of 380-420 kV series capacitors

Equipment	Number of units in 2021	Number of failures in 2021	Based data from
380-420 kV series capacitors	17	10	SvK

90 Table 11.1.2: Outage duration of 380-420 kV series capacitors

Equipment	Year	Number of failures recorded with outage time	Total outage time (h)	Outage time (h/f)	Based data from
380-420 kV series capacitors	2018	1	27,52	27,52	SvK
	2019	8	126,58	15,82	
	2020	12	286,10	23,84	
	2021	10	473,62	47,36	

91 Table 11.1.3: Reliability data of 380-420 kV series capacitors

Equipment	Failure rate in 2021 (f/yr.unit)	Failure rate, 10-year annual average in 2012-2021 (f/yr.unit)	Outage time in 2021 (h/f)	Outage time, 4-year average in 2018-2021 (h/f)	Availability in 2021	Availability, 4-year average in 2018-2021	Based data from
380-420 kV series capacitors	0,58824	0,52500	47,36	29,48	99,681963%	99,82333%	SvK

11.2 RECOMMENTED STATISTICS FOR SERIES CAPACITORS

The recommended reliability data for 380-420 kV series capacitors are summarized in the table 11.2.1 below.

92 Table 11.2.1: Recommended reliability data for 380-420 kV series capacitors

Equipment	Failure rate, 10-year annual average in 2012-2021 (f/yr.unit)	Outage time, 4-year average in 2018-2021 (h/f)	Availability, 4-year average in 2018-2021	Based data from
380-420 kV series capacitors	0,52500	29,48	99,82333%	SvK

12 Reliability Data of Shunt Capacitors

A shunt capacitor is a capacitor connected in parallel to a load or a supply point. Shunt capacitors have several uses in the power systems. They are utilized as sources of reactive power. They are usually called "power factor correction capacitors", although they also serve other functions and provide multiple benefits. In power systems, a large portion of load is inductive, like motors, transformers, electromagnetic devices etc., causing a low power factor due to this lagging load. Shunt capacitors are used across load or on lines to offer leading load. This counteracts the lagging load and improves power factor, and thus improves overall system efficiency. They are used at all voltage levels.

This chapter presents the fault statistics of shunt capacitors based on the grid disturbance statistics published by the ENTSO-E and the outage records collected by SvK during 2018-2021 [1, 5, 6].

The outage database at Energiföretagen contains no equipment data nor fault occurrence data for shunt capacitors from the Swedish DSOs during 2014-2021, therefore no reliability statistics could be generated based on the data from the Swedish DSOs.

12.1 SVK STATISTICS

Component shunt capacitors considered in fault statistics by SvK include the following sub-components:

- Capacitor;
- Reactor;
- Resistor;
- Support isolator;
- Power capacitor if power transformer is designed exclusively for shunt capacitor or filter;
- Surge arresters if integrated in shunt capacitor battery or filter;
- Instrument transformer if integrated in shunt capacitor battery or filter.

The following tables present faults statistics for shunt capacitors.

Table 12.1.1 presents the number of 100-420 kV shunt capacitors and number of faults in 2021.

Table 12.1.2 shows outage duration of 100-420 kV shunt capacitors during 2018-2021, and the table 12.1.3 gives the reliability data deduced for 100-420 kV series capacitors.

93 Table 12.1.1 Number of 100-420 kV shunt capacitors and failures

Equipment	Number of units in 2021	Number of failures in 2021	Based data from
100-420 kV shunt capacitors	153	1	SvK

94 Table 12.1.2: Outage duration of 100-420 kV shunt capacitors

Equipment	Year	Number of failures recorded with outage time	Total outage time (h)	Outage time (h/f)	Based data from
100-420 kV shunt capacitors	2018	1	2,03	2,03	SvK
	2019	0	0,00	0,00	
	2020	1	9,57	9,57	
	2021	1	174,13	174,13	

95 Table 12.1.3: Reliability data of 100-420 kV shunt capacitors

Equipment	Failure rate in 2021 (f/yr.unit)	Failure rate, 10-year annual average in 2012-2021 (f/yr.unit)	Outage time in 2021 (h/f)	Outage time, 4-year average in 2018-2021 (h/f)	Availability in 2021	Availability, 4-year average in 2018-2021	Based data from
100-420 kV shunt capacitors	0,00654	0,00800	174,13	61,91	99,987008%	99,99435%	SvK

12.2 RECOMMENTED STATISTICS FOR SHUNT CAPACITORS

The recommended reliability data for 100-400 kV shunt capacitors are summarized in the table 12.2.1 below.

96 Table 12.2.1: Recommended reliability data for 100-420 kV shunt capacitors

Equipment	Failure rate, 10-year annual average in 2012-2021 (f/yr.unit)	Outage time, 4-year average in 2018-2021 (h/f)	Availability, 4-year average in 2018-2021	Based data from
100-420 kV shunt capacitors	0,00800	61,91	99,99435%	SvK

13 Reliability Data of SVC Devices

SVC (Static Var Compensator) and STATCOM (Static Synchronous Compensator) are shunt devices in the FACTS family used on power systems. The initial device, SVC, based on high power thyristor technology, appeared in the field in the 1970s. STATCOM, based on GTO (Gate Turn-off Thyristors) came into use in the 1980s, and subsequently, with high power IGBT (Insulated Gate Bipolar Transistor) becoming commercially available, STATCOM based on this technology platform came on line in the 1990s. With application of SVC and STATCOM on power systems, the transmission capability of power lines can be increased considerably, and the transient voltage behavior of power systems can be significantly improved.

This chapter presents the fault statistics of SVC and STATCOM based on the grid disturbance statistics published by the ENTSO-E and the outage records collected by SvK during 2018-2021 [1, 5, 6].

The outage database at Energiföretagen contains no equipment data nor fault occurrence data for SVC and STATCOM from the Swedish DSOs during 2014-2021, therefore no reliability statistics could be generated based on the data from the Swedish DSOs.

13.1 SVK STATISTICS

Component SVC and STATCOM considered by SvK in the fault statistics include the following sub-components:

- Ancillary equipment;
- Capacitor;
- Integrated control equipment;
- Cooling;
- Reactor;
- Power capacitor, if power capacitor is exclusively designed for SVC or STATCOM;
- Valves, i.e., semiconductors such as GTO and IGBT.

SVC and STATCOM are considered as one component per unit.

The following tables present fault statistics for SVC and STATCOM.

Table 13.1.1 presents the number of 100-420 kV SVC and STATCOM and number of faults in 2021.

Table 13.1.2 shows outage duration of 100-420 kV SVC and STATCOM during 2018-2021, and the table 13.1.3 gives the reliability data deduced for 100-420 kV series capacitors.

97 Table 13.1.1 Number of 100-420 kV SVC devices and failures

Equipment	Number of units in 2021	Number of failures in 2021	Based data from
100-420 kV SVC devices	3	1	SvK

98 Table 13.1.2: Outage duration of 100-420 kV SVC devices

Equipment	Year	Number of failures recorded with outage time	Total outage time (h)	Outage time (h/f)	Based data from
100-420 kV SVC devices	2018	2	24,58	12,29	SvK
	2019	2	12,03	6,02	
	2020	2	4,73	2,37	
	2021	1	1,72	1,72	

99 Table 13.1.3: Reliability data of 100-420 kV SVC devices

Equipment	Failure rate in 2021 (f/yr.unit)	Failure rate, 10-year annual average in 2012-2021 (f/yr.unit)	Outage time in 2021 (h/f)	Outage time, 4-year average in 2018-2021 (h/f)	Availability in 2021	Availability, 4-year average in 2018-2021	Based data from
100-420 kV SVC devices	0,33333	2,10900	1,72	6,15	99,993455%	99,85187%	SvK

13.2 RECOMMENTED STATISTICS FOR SVC DEVICES

The recommended reliability data for 100-420 kV SVC and STATCOM are summarized in the table 13.2.1 below.

100 Table 13.2.1: Recommended reliability data for 100-420 kV SVC devices

Equipment	Failure rate, 10-year annual average in 2012-2021 (f/yr.unit)	Outage time, 4-year average in 2018-2021 (h/f)	Availability, 4-year average in 2018-2021	Based data from
100-420 kV SVC devices	2,10900	6,15	99,85187%	SvK

14 Reliability Data of Power Stations

Power stations (or substations) are the critical parts of a power system because they are the points in the system where the main power components interconnect. Power stations are placed at different points on a power system. The purpose of a power station is to step down high voltage electricity to lower voltage electricity. They connect different parts of the power network and serve as a source of transmission or distribution lines. An important function performed by a power station is switching, connecting or disconnecting transmission lines or other components to and from the power system.

A power station is an aggregated block of power components. It may include power transformer, switch devices, circuit breakers, current or voltage transformers, lightning arrester, control equipment, etc. Traditionally reliability of a power station is assessed in detail level based on the reliability of individual components contained in the station. In the fault database at Energiföretagen there are quite good data and associated information about the faults occurred on power stations at different voltage levels. This allows to treat the station as a whole aggregated unit and offers the possibility of generating reliability data directly for the stations.

This chapter presents the reliability data generated for the power stations at the voltages of 36 kV, 45 kV, 66 kV and 130 kV respectively according to the outage data and the station population data submitted by the Swedish DSOs during 2014-2021.

The ENTSO-E fault report and the outage records by SvK contain no faults data for power stations, therefore no reliability statistics could be generated for power stations at voltages of 220 kV and 400 kV.

14.1 130 KV POWER STATIONS

Table 14.1.1 shows the number of power stations and the failure rate and outage duration of 130 kV power stations. Table 14.1.2 presents the reliability data deduced for 130 kV power stations.

101 Table 14.1.1: Failure rate and outage time of 130 kV power stations

Equipment	Year	Number of stations	Number of failures with outage duration > 0	Total outage time (h)	Failure rate (f/yr.station)	Outage time (h/f)	Based data from
130 kV power station (Regionstation, fördelningsstation)	2014		102	1488,20		14,59	All Swedish DSOs
	2015		78	97,15		1,25	
	2016		112	501,53		4,48	
	2017		130	350,50		2,70	
	2018	386	166	3677,27	0,43005	22,15	
	2019		170	1168,00		6,87	
	2020		96	409,00		4,26	
	2021	412	39	135,95	0,09466	3,49	

102 Table 14.1.2: Reliability data of 130 kV power stations

Equipment	Failure rate in 2021 (f/yr.station)	Failure rate, 8-year average in 2014-2021 (f/yr.station)	Outage time in 2021 (h/f)	Outage time, 8-year average in 2014-2021 (h/f)	Availability in 2021	Availability, 8-year average in 2014-2021	Based data from
130 kV power station (regionstation, fördelningsstation)	0,09466	0,27976	3,49	8,77	99,99623 %	99,97201%	All Swedish DSOs

14.2 66 KV POWER STATIONS

Table 14.2.1 shows the number of power stations and the failure rate and outage duration of 66 kV power stations. Table 14.2.2 presents the reliability data deduced for 66 kV power stations.

103 Table 14.2.1: Failure rate and outage time of 66 kV power stations

Equipment	Year	Number of stations	Number of failures with outage duration > 0	Total outage time (h)	Failure rate (f/yr.station)	Outage time (h/f)	Based data from
66 kV power station (Regionstation, fördelningsstation)	2014	52	22	19,55	0,42308	0,89	All Swedish DSOs
	2015		11	9,22		0,84	
	2016		12	14,97		1,25	
	2017		23	18,38		0,80	
	2018	47	32	68,37	0,68085	2,14	
	2019	49	29	306,60	0,59184	10,57	
	2020	51	16	7,33	0,31373	0,46	
	2021		12	3,68		0,31	

104 Table 14.2.2: Reliability data of 66 kV power stations

Equipment	Failure rate in 2020 (f/yr.station)	Failure rate, 8-year average in 2014-2021 (f/yr.station)	Outage time in 2020 (h/f)	Outage time, 8-year average in 2014-2021 (h/f)	Availability in 2021	Availability, 8-year average in 2014-2021	Based data from
66 kV power station (regionstation, fördelningsstation)	0,31373	0,39447	0,46	2,85	99,99836%	99,98715%	All Swedish DSOs

14.3 45 KV POWER STATIONS

Table 14.3.1 shows the number of power stations and the failure rate and outage duration of 45 kV power stations. Table 14.3.2 presents the reliability data deduced for 45 kV power stations.

105 Table 14.3.1: Failure rate and outage time of 45 kV power stations

Equipment	Year	Number of stations	Number of failures with outage duration > 0	Total outage time (h)	Failure rate (f/yr.station)	Outage time (h/f)	Based data from
45 kV power station (Regionstation, fördelningsstation)	2014	424	130	680,42	0,30660	5,23	All Swedish DSOs
	2015		91	280,98		3,09	
	2016		93	381,07		4,10	
	2017	454	79	401,55	0,17401	5,08	
	2018	509	117	407,97	0,22986	3,49	
	2019		110	424,83		3,86	
	2020		80	394,78		4,93	
	2021	471	59	52,18	0,12527	0,88	

106 Table 14.3.2: Reliability data of 45 kV power stations

Equipment	Failure rate in 2021 (f/yr.station)	Failure rate, 8-year average in 2014-2021 (f/yr.station)	Outage time in 2021 (h/f)	Outage time, 8-year average in 2014-2021 (h/f)	Availability in 2021	Availability, 8-year average in 2014-2021	Based data from
45 kV power station (regionstation, fördelningsstation)	0,12527	0,20425	0,88	3,98	99,99874%	99,99071%	All Swedish DSOs

14.4 36 KV POWER STATIONS

Table 14.4.1 shows the number of power stations and the failure rate and outage duration of 36 kV power stations. Table 14.4.2 presents the reliability data deduced for 36 kV power stations.

107 Table 14.4.1: Failure rate and outage time of 36 kV power stations

Equipment	Year	Number of stations	Number of failures with outage duration > 0	Total outage time (h)	Failure rate (f/yr.station)	Outage time (h/f)	Based data from
36 kV power station (Regionstation, fördelningsstation)	2014		5	33,38		6,68	All Swedish DSOs
	2015		14	187,70		13,41	
	2016		15	21,47		1,43	
	2017	74	33	39,30	0,44595	1,19	
	2018	74	16	185,68	0,21622	11,61	
	2019		11	30,68		2,79	
	2020		13	372,03		28,62	
	2021	74	14	36,62	0,18919	2,62	

108 Table 14.4.2: Reliability data of 36 kV power stations

Equipment	Failure rate in 2021 (f/yr.station)	Failure rate, 8-year average in 2014-2021 (f/yr.station)	Outage time in 2021 (h/f)	Outage time, 8-year average in 2014-2021 (h/f)	Availability in 2021	Availability, 8-year average in 2014-2021	Based data from
36 kV power station (regionstation, fördelningsstation)	0,18919	0,20439	2,62	7,49	99,99435%	99,98251%	All Swedish DSOs

14.5 RECOMMENTED STATISTICS FOR POWER STATION

The recommended reliability data for 36-130 kV power stations are summarized in the table 14.5.1 below.

109 Table 14.5.1: Recommended reliability data for 36-130 kV power stations

Equipment	Failure rate, 8-year average in 2014-2021 (f/yr.station)	Outage time, 8-year average in 2014-2021 (h/f)	Availability, 8-year average in 2014-2021	Based data from
130 kV power station (regionstation, fördelningsstation)	0,27976	8,77	99,97201%	All Swedish DSOs
66 kV power station (regionstation, fördelningsstation)	0,39447	2,85	99,98715%	
45 kV power station (regionstation, fördelningsstation)	0,20425	3,98	99,99071%	
36 kV power station (regionstation, fördelningsstation)	0,20439	7,49	99,98251%	

15 Reliability Data of Power Switching Stations

A power switching station is a type of substation that usually does not contain power transformers and hence does not change system voltage from one level to another. The function of a switching station is to tie together two or more circuits of a power system through switches. In a switching station, the switches are selectively arranged to permit circuits to be connected or disconnected or to change the connections between the circuits.

A switching station is an aggregated block of power components, it normally contains circuit breakers, switches, current or/and voltage transformers, and lightning arresters. Normally reliability of a switching station is calculated on component level based on the reliability data of individual components contained in the station. In the fault database at Energiföretagen there are good data and associated information about the faults occurred on switching stations at voltage levels of 45 kV and 36 kV. This gives the possibility to deduce reliability data for switching stations on station overall level.

This chapter presents the reliability data generated for the switching stations at the voltages of 36 kV and 45 kV respectively according to the outage data and the station population data submitted by the Swedish DSOs during 2014-2021.

There are no population data for 66-130 kV switching stations in the fault database at Energiföretagen. The ENTSO-E fault report and the outage records by SvK contain no fault data for switching stations, therefore no reliability statistics could be produced for switching stations at voltage levels of 66-400 kV.

15.1 45 KV POWER SWITCHING STATIONS

Table 15.1.1 shows the number of switching stations and the failure rate and outage duration of 45 kV switching stations. Table 15.1.2 presents the reliability data deduced for 45 kV switching stations.

110 Table 15.1.1: Failure rate and outage time of 45 kV power switching stations

Equipment	Year	Number of stations	Number of failures with outage duration > 0	Total outage time (h)	Failure rate (f/yr.station)	Outage time (h/f)	Based data from
45 kV power switching station (kopplingsstation)	2014		4	13,55		3,39	All Swedish DSOs
	2015		3	2,58		0,00	
	2016	27	0	0,00	0,00000	0,00	
	2017		2	0,63		0,32	
	2018		1	0,08		0,08	
	2019		0	0,00	0,00000	0,00	
	2020		0	0,00	0,00000	0,00	
	2021		0	0,00	0,00000	0,00	

111 Table 15.1.2: Reliability data of 45 kV power switching stations

Equipment	Failure rate in 2021 (f/yr.station)	Failure rate, 8-year average in 2014-2021 (f/yr.station)	Outage time in 2021 (h/f)	Outage time, 8-year average in 2014-2021 (h/f)	Availability in 2021	Availability, 8-year average in 2014-2021	Based data from
45 kV power switching station (kopplingsstation)	0,00000	0,04630	0,00	1,68	100,00000%	99,99911%	All Swedish DSOs

15.2 36 KV POWER SWITCHING STATIONS

Table 15.2.1 shows the number of switching stations and the failure rate and outage duration of 36 kV switching stations. Table 15.2.2 presents the reliability data deduced for 36 kV switching stations.

112 Table 15.2.1: Failure rate and outage time of 36 kV power switching stations

Equipment	Year	Number of stations	Number of failures with outage duration > 0	Total outage time (h)	Failure rate (f/yr.station)	Outage time (h/f)	Based data from
36 kV power switching station (kopplingsstation)	2014		1	4,05		4,05	All Swedish DSOs
	2015		0	0,00		0,00	
	2016		0	0,00		0,00	
	2017	35	3	1,85	0,08571	0,62	
	2018	35	3	83,13	0,08571	27,71	
	2019		2	50,70		25,35	
	2020		0	0,00		0,00	
	2021	36	0	0,00	0,00000	0,00	

113 Table 15.2.2: Reliability data of 36 kV power switching stations

Equipment	Failure rate in 2021 (f/yr.station)	Failure rate, 8-year average in 2014-2021 (f/yr.station)	Outage time in 2021 (h/f)	Outage time, 8-year average in 2014-2021 (h/f)	Availability in 2021	Availability, 8-year average in 2014-2021	Based data from
36 kV power switching station (kopplingsstation)	0,00000	0,03184	0,00	15,53	100,00000%	99,99436%	All Swedish DSOs

15.3 RECOMMENTED STATISTICS FOR POWER SWITCHING STATIONS

The recommended reliability data for 36-45 kV switching stations are summarized in the table 15.3.1 below.

114 Table 15.3.1: Recommended reliability data for 36-45 kV power switching stations

Equipment	Failure rate, 8-year average in 2014-2021 (f/yr.station)	Outage time, 8-year average in 2014-2021 (h/f)	Availability, 8-year average in 2014-2021	Based data from
45 kV power switching station (kopplingsstation)	0,04630	1,68	99,99911%	All Swedish DSOs
36 kV power switching station (kopplingsstation)	0,03184	15,53	99,99436%	

16 Conclusion

In reliability analysis of a power system, power supply reliability is calculated from the knowledge of the reliability data of individual components contained in the system. Meaningful reliability analysis requires reasonable and acceptable data. The quality of the data has the fundamental importance for the analysis. However, the valid data are expensive to collect. The component reliability performance statistics are not easy to obtain.

This report presents the high voltage equipment reliability data produced by the project “Reliability Data for High Voltage Components" within the Energiforsk program “Risk- och tillförlitlighetsanalys 2021-2025”. The project analyzed a large sample size of outages caused by faults on high voltage components recorded by SvK and more than a hundred power utilities in Sweden during 2014–2021, and derived the equipment reliability data nationwide. The detailed summaries of these data are presented in the report.

The component reliability was also analyzed at power utility level. The fault data from Vattenfall Distribution Sweden and E.ON Energidistribution AB were studied separately. The reliability data were derived for these companies for those components with good faults data and population information. The detailed data lists and fault statistics are summarized in the report for each companies.

The reliability data produced for each component category considered in the project include three basic statistics:

- sustained failure rate (f/yr.unit);
- outage duration (h/f)
- availability (%)

The number of components and equipment population data are the basis for estimating reliability data, these statistics are also documented in the report together with the associated fault statistics for whole Sweden and for individual power utilities

The power components considered in the report cover operating voltages of 36 kV, 45 kV, 66 kV, 130 kV, 220 kV and 400 kV, and include the following 10 categories:

- overhead line;
- power cable;
- power transformer;
- circuit breaker;
- control equipment;
- instrument transformer;
- reactor;
- series capacitor;
- shunt capacitor;
- SVC device.

Disconnectors (frånskiljare) is one of major categories of power components used in power systems. However the fault data and population data for disconnectors

submitted to Energiföretagen by Swedish DSOs are mainly on voltages of 0,4-24 kV, the data for disconnectors at high voltages of 36 kV and above are insufficient. There isn't either fault statistics for disconnectors reported by SvK. The reliability data for disconnectors therefore could not be achieved by the project.

In addition to power components the reliability statistics are also produced for power stations with operation voltages of 36 kV, 45 kV, 66 kV and 130 kV, as well as for power switching stations on voltages of 36 kV and 45 kV.

Component reliability can be affected by a number of factors. These reliability influencing factors include weather and environmental conditions, line exposure, operation and maintenance practice, and restoration methods. The reliability data given in this report represent component average performance statistics and should be regarded as generic.

It should be emphasized that the best data are one's own data since all related attributes should then be known. When own data are unavailable, or when it may not be possible to collect all of own data, it is necessary to use generic data. The data presented in this report are produced based on a large sample size of field outage records and can be therefore used as generic data in power system reliability studies.

17 References

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Appendix A: Recommendation of reliability data statistics

This appendix summarizes all the recommended component reliability data presented in the report.

A.1 RECOMMENTED STATISTICS FOR OVERHEAD LINES

Table A.1.1: Reliability data for 36-400 kV overhead lines

Equipment	Failure rate, 10-year annual average in 2012-2021 (f/yr.km),	Outage time, 4-year average in 2018-2021 (h/f)	Availability, 4-year annual average in 2018-2021	Based data from	Remarks
400 kV overhead line (all types)	0,00340	4,14	99,99984%	SvK	For faults with outage duration > 0 (including temporary and short duration faults)
220 kV overhead line (all types)	0,00730	3,48	99,99971%		
130 kV overhead line (all types)	0,01420	1,76	99,99972%		
Equipment	Failure rate, 8-year annual average in 2014-2021 (f/yr.km)	Outage time, 8-year average in 2014-2021 (h/f)	Availability, 8-year annual average in 2014-2021	Based data from	Remarks
130 kV overhead line bare, (Friledning, oisolerad)	0,00184	4,93	99,99990%	All Swedish DSOs	For sustainable permanent outages
Equipment	Failure rate, 3-year annual average in 2019-2021 (f/yr.km)	Outage time, 8-year average in 2014-2021 (h/f)	Availability, 3-year annual average in 2014-2021	Based data from	Remarks
66 kV overhead line bare, (Friledning, oisolerad)	0,00355	4,78	99,99981%	All Swedish DSOs	For faults with outage duration > 0
Equipment	Failure rate, 6-year annual average in 2014-2021 (f/yr.km)	Outage time, 8-year average in 2014-2021 (h/f)	Availability, 6-year annual average in 2014-2021	Based data from	Remarks

45 kV overhead line bare, (Friledning, oisolerad)	0,00570	4,09	99,99973%	All Swedish DSOs	For faults with outage duration > 0
Equipment	Failure rate, 3-year annual average in 2017-2021 (f/yr.km)	Outage time, 8-year average in 2014-2021 (h/f)	Availability, 3-year annual average in 2017-2021	Based data from	Remarks
36 kV overhead line bare, (Friledning, oisolerad)	0,01728	3,54	99,99930%	All Swedish DSOs	For faults with outage duration > 0

A.2 RECOMMENTED STATISTICS FOR POWER CABLES

Table A.2.1: Recommended failure rate of 220-400 kV underground cables

Equipment	Failure rate, 10-year annual average in 2012-2021 (f/yr.km)	Based data from
400 kV underground cable	0,02750	SvK
220 kV underground cable	0,01710	SvK

Table A.2.2: Recommended reliability data for 36-130 kV power cables

Equipment	Failure rate, 8-year average in 2014-2021 (f/yr.km)	Outage time, 8-year average in 2014-2021 (h/f)	Availability, 8-year average in 2014-2021	Based data from
130 kV underground cable (kabel i mark)	0,00718	14,52	99,99881%	All Swedish DSOs
66 kV underground cable (kabel i mark)	0,00893	2,83	99,99971%	
45 kV underground cable (kabel i mark)	0,00688	17,15	99,99865%	
45 kV power cable above ground and aerial (friledning isolerad)	0,03177	1,14	99,99959%	
36 kV underground cable (kabel i mark)	0,00973	26,72	99,99703%	
36 kV power cable above ground and aerial (friledning isolerad)	0,17469	7,00	99,98605%	
36 kV under water cable (kabel i vatten)	0,01963	61,21	99,98629%	

A.3 RECOMMENTED STATISTICS FOR POWER TRANSFORMERS

Table A.3.1: Recommended reliability data for 30-400 kV power transformers

Equipment	Failure rate, 10-year annual average in 2012-2021 (f/yr.unit)	Outage time, 4-year average in 2018-2021 (h/f)	Availability, 4-year average in 2018-2021	Based data from
100-150 kV power transformer	0,02320	9,73	99,99742%	SvK
220-330 kV power transformer	0,03040	7,81	99,99729%	
Equipment	Failure rate, 14-year average in 2006-2019 (f/yr.unit),	Outage time, 14-year average in 2006-2019 (h/f)	Availability, 14-year annual average in 2006-2019	Based data from
30-70 kV power transformer	0,00542	6,13	99,99962%	Vattenfall
130-400 kV power transformer	0,00566	9,66	99,99938%	

A.4 RECOMMENTED STATISTICS FOR CIRCUIT BREAKERS

Table A.4.1: Recommended reliability data for 100-420 kV circuit breakers

Equipment	Failure rate, 10-year annual average in 2012-2021 (f/yr.unit),	Outage time, 4-year average in 2018-2021 (h/f)	Availability, 4-year average in 2018-2021	Based data from
100-150 kV circuit breaker	0,00180	9,81	99,99980%	SvK
220-330 kV circuit breaker	0,00400	26,67	99,99878%	
380-420 kV circuit breaker	0,00810	19,81	99,99817%	

A.5 RECOMMENTED STATISTICS FOR CONTROL EQUIPMENT

Table A.5.1: Recommended reliability data for 100-420 kV control equipment

Equipment	Failure rate, 10-year annual average in 2012-2021 (f/yr.unit)	Outage time, 4-year average in 2018-2021 (h/f)	Availability, 4-year average in 2018-2021	Based data from
100-150 kV control equipment	0,00750	13,61	99,99883%	SvK
220-330 kV control equipment	0,03730	20,43	99,99130%	
380-420 kV control equipment	0,04160	17,42	99,99173%	

A.6 RECOMMENTED STATISTICS FOR INSTRUMENT TRANSFORMERS

Table A.6.1: Recommended reliability data for 100-420 kV instrument transformers

Equipment	Failure rate, 10-year annual average in 2012-2021 (f/yr.unit)	Outage time, 4-year average in 2018-2021 (h/f)	Availability, 4-year average in 2018-2021	Based data from
100-150 kV instrument transformer	0,00080	27,23	99,99975%	SvK
220-330 kV instrument transformer	0,00020	42,57	99,99990%	
380-420 kV instrument transformer	0,00090	40,67	99,99958%	

A.7 RECOMMENTED STATISTICS FOR REACTORS

Table A.7.1: Recommended reliability data for 220-420 kV reactors

Equipment	Failure rate, 10-year annual average in 2012-2021 (f/yr.unit)	Outage time, 4-year average in 2018-2021 (h/f)	Availability, 4-year average in 2018-2021	Based data from
220-420 kV reactor	0,01900	32,23	99,99301%	SvK

A.8 RECOMMENTED STATISTICS FOR SERIES CAPACITORS

Table A.8.1: Recommended reliability data for 380-420 kV series capacitors

Equipment	Failure rate, 10-year annual average in 2012-2021 (f/yr.unit)	Outage time, 4-year average in 2018-2021 (h/f)	Availability, 4-year average in 2018-2021	Based data from
380-420 kV series capacitors	0,52500	29,48	99,82333%	SvK

A.9 RECOMMENTED STATISTICS FOR SHUNT CAPACITORS

Table A.9.1: Recommended reliability data for 100-420 kV shunt capacitors

Equipment	Failure rate, 10-year annual average in 2012-2021 (f/yr.unit)	Outage time, 4-year average in 2018-2021 (h/f)	Availability, 4-year average in 2018-2021	Based data from
100-420 kV shunt capacitors	0,00800	61,91	99,99435%	SvK

A.10 RECOMMENTED STATISTICS FOR SVC DEVICES

Table A.10.1: Recommended reliability data for 100-420 kV SVC devices

Equipment	Failure rate, 10-year annual average in 2012-2021 (f/yr.unit)	Outage time, 4-year average in 2018-2021 (h/f)	Availability, 4-year average in 2018-2021	Based data from
100-420 kV SVC devices	2,10900	6,15	99,85187%	SvK

A.11 RECOMMENTED STATISTICS FOR POWER STATIONS

Table A.11.1: Recommended reliability data for 36-130 kV power stations

Equipment	Failure rate, 8-year average in 2014-2021 (f/yr.station)	Outage time, 8-year average in 2014-2021 (h/f)	Availability, 8-year average in 2014-2021	Based data from
130 kV power station (regionstation, fördelningsstation)	0,27976	8,77	99,97201%	All Swedish DSOs
66 kV power station (regionstation, fördelningsstation)	0,39447	2,85	99,98715%	
45 kV power station (regionstation, fördelningsstation)	0,20425	3,98	99,99071%	
36 kV power station (regionstation, fördelningsstation)	0,20439	7,49	99,98251%	

A.12 RECOMMENTED STATISTICS FOR POWER SWITCHING STATIONS

Table A.12.1: Recommended reliability data for 36-45 kV power switching stations

Equipment	Failure rate, 8-year average in 2014-2021 (f/yr.station)	Outage time, 8-year average in 2014-2021 (h/f)	Availability, 8-year average in 2014-2021	Based data from
45 kV power switching station (kopplingsstation)	0,04630	1,68	99,99911%	All Swedish DSOs
36 kV power switching station (kopplingsstation)	0,03184	15,53	99,99436%	

HIGH VOLTAGE EQUIPMENT RELIABILITY DATA

Component outages are the root cause of a system failure. In the reliability analysis of a power system, the system performance can be evaluated from the knowledge of the reliability data of system components. The reliability and failure characteristics of the components are described by their reliability data. Meaningful reliability analysis requires reasonable and acceptable component reliability data. The quality of the data has the fundamental importance for the reliability analysis. At present, there is a lack of reliable failure statistics for high voltage components at power industry level. Power branch wide data support is needed for risk and reliability analyses.
This report presents the high voltage equipment reliability data. The reliability data were deduced nationwide based on a large sample size of outages caused by faults on high voltage components recorded by SvK as well as by more than a hundred power utilities in Sweden during 2014–2021. The component reliability has also been analyzed at power utility level. The fault data from Vattenfall Distribution Sweden and E.ON Energidistribution AB were studied, and the reliability data were derived for these companies.
The power components considered in the report cover operating voltages of 36 kV, 45 kV, 66 kV, 130 kV, 220 kV and 400 kV, and include ten categories of power components. In addition to power components the reliability statistics are also produced for power stations with operation voltages of 36 kV, 45 kV, 66 kV and 130 kV, as well as for power switching stations on voltages of 36 kV and 45 kV.

The reliability data presented in this report are produced based on a large sample size of field outage records, these reliability data represent component average performance statistics and can be therefore used as generic data in power system reliability analysis.

Ett nytt steg i energiforskningen

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