IMP/001/011 – Code of Practice for Overhead Line Ratings and Parameters

1. Purpose

The purpose of this document is to state Northern Powergrid's policy for the derivation of ratings and the parameters to be applied when designing overhead line systems. The document applies to the distribution system of both Northern Powergrid (Northeast) plc and Northern Powergrid (Yorkshire) plc, the licensed distributors of Northern Powergrid.

This Code of Practice helps to ensure the company achieves its requirements with respect to the Electricity Act 1989 (as amended by the Utilities Act 2000 and the Energy Act 2004), The Electricity Safety, Quality and Continuity (ESQC) Regulations 2002 (as amended)[1], the Health and Safety at Work Act 1974, the Electricity Distribution Licences, The Distribution Code and The Grid Code.

This document supersedes the following documents, all copies of which should be removed from circulation.

Reference	Version	Date	Title
IMP/001/011	4.0	Dec 2017	Code of Practice for Guidance on the Selection of Overhead Line Ratings

2. Scope

The parameters stated in this document apply to:

- existing overhead line conductors at all voltage levels; and
- new overhead line conductors at all voltage levels installed as part of distribution system developments including new connections, system reinforcement and asset replacement.

Ratings are given for winter, spring/autumn and summer conditions in both amps and MVA (at nominal voltage). This document applies to the overhead line portion of a circuit only, and should not be applied to associated equipment (e.g. transformers or underground cables).

The rating of an overhead line is dependent upon the:

- overhead line construction specification;
- conductor maximum design temperatures (50°C, 65°C or 75°C); and
- circuit topology in which the overhead line is used.

This document does not provide guidance on:

- the overhead line design specifications that should be utilised for new build or refurbishment of overhead lines nor the size and type of conductor that should be utilised for a specific application. This can be found in:
    - Code of Practice for the Construction of LV ABC Overhead Lines, NSP/004/041;
    - Specification for HV Wood Pole Lines up to and including 33kV, NSP/004/042;
    - Specification for Overhead Services, Surface Wiring and Eaves Wall Mains, NSP/004/043;

[1] This includes The ESQC (Amendment) Regulations 2006 (No. 1521, 1st October 2006) and The ESQC (Amendment) Regulations 2009 (No. 639, 6th April 2009).

- Specification of HV Wood Pole Lines of Compact Covered Construction up to and including 33kV, NSP/004/044;
- Code of Practice for EHV Wood Pole Lines operating up to 132kV with span lengths up to 220m, NSP/004/045;
- Code of Practice for the Economic Development of the 132kV system, IMP/001/914;
- Code of Practice for the Economic Development of the EHV system, IMP/001/913;
- Code of Practice for the Economic Development of the HV system, IMP/001/912; and
- Code of Practice for the Economic Development of the LV system, IMP/001/911.
- the methods available to up-rate existing overhead lines in accordance with:
- Code of Practice for the Survey of Overhead Line Routes, NSP/004/031.
- the required statutory overhead line clearances, which are set out in:
- Code of practice for Overhead Line Clearances, NSP/004/011.
- sag and tension calculations, which are set out in:
- Guidance on the selection, election and sagging of O/H line conductors, NSP/004/105.

2.1 Table of Contents

3. Code of Practice

3.1 Assessment of Relevant Drivers

The key internal business drivers relating to the derivation of ratings and parameters to be applied when designing overhead line systems are:

- Employee commitment - achieved by providing our employees with the information necessary to develop a safe distribution system that is fit for purpose and to help ensure that employees are not exposed to risks to their health as far as reasonably practicable;
- Financial strength - achieved by developing a distribution system that has a minimum overall lifetime cost;
- Customer service - achieved by providing information on equipment ratings and other parameters to third parties who are interested in a connection to Northern Powergrid's distribution system;
- Regulatory integrity - achieved by designing a robust distribution system that meets mandatory and recommended standards;
- Environmental respect - achieved through due consideration being given to the environmental impact of new developments including the impact on system losses and carbon footprint; and
- Operational excellence - achieved through improving the quality, availability and reliability of supply.

The external business drivers relating to the selection and application of overhead line ratings are detailed in the following sections.

3.1.1 Requirements of the Electricity Act 1989 (as amended)[2]

Section 9 (1) of the Electricity Act 1989 (as amended) places an obligation on Distribution Network Operators (DNOs) to develop and maintain an efficient, co-ordinated and economical system of electricity distribution and to facilitate competition in the supply and generation of electricity.

Discharge of this obligation is supported by this document in providing guidance on the application of appropriate overhead line ratings.

3.1.2 The Health and Safety at Work Act 1974

Section 2(1) of The Health and Safety at work Act 1974, states that 'It shall be the duty of every employer to ensure, so far as is reasonably practicable, the health, safety and welfare at work of all his employees.' Section 3(1) also states that 'It shall be the duty of every employer to conduct his undertaking in such a way as to ensure, so far as is reasonably practicable, that persons not in his employment who may be affected thereby are not thereby exposed to risks to their health or safety.'

This is addressed in this Code of Practice by:

- Stating the continuous seasonal ratings appropriate to overhead lines forming the distribution system;
- Stating the assumptions associated with these ratings; and
- Providing impedance data so that short circuit levels can be calculated accurately.

3.1.3 Requirements of the Electricity Safety, Quality and Continuity (ESQC) Regulations

The ESQC Regulations 2002 (No.2665, 31st January 2003) and its amendments[3] impose a number of obligations on the business, mainly relating to safety and quality of supply. All the requirements of the ESQC

[2] The Utilities Act 2000 and The Energy Act 2004 and The Energy Act 2004 (Amendment) Regulations 2012 (No. 2723, 2012).

[3] This includes The ESQC (Amendment) Regulations 2006 (No. 1521, 1st October 2006) and The ESQC (Amendment) Regulations 2009 (No. 639, 6th April 2009).

Regulations that are applicable to the design and development of the distribution system shall be complied with.

Reg. No	Text	Application to this Code of Practice
3(1)(a) & 3(1)(b)	…distributors…shall ensure that their equipment is sufficient for the purposes for and the circumstances in which it is used; and so constructed, installed…used as to prevent danger…or interruption of supply, so far as is reasonably practicable.	This Code of Practice will contribute to compliance with the ESQC Regulations by providing overhead line parameters for any analysis which is required to be carried out to ensure that the continuous seasonal and short circuit duties to which equipment is exposed is within its capability.
17	...the height above ground of any overhead line, at the maximum likely temperature of that line, shall not be less than the specified…	This Code of Practice will contribute to compliance with the ESQC Regulations by providing guidance on the application of appropriate overhead line ratings to help ensure that the probability of statutory clearances being infringed is in accordance with good industry practice.

3.1.4 Requirements of the Electricity at Work Regulations 1989

Regulation 5 of The Electricity at Work Regulations 1989 states: 'No electrical equipment shall be put into use where its strength and capability may be exceeded in such a way as may give rise to danger' and places obligations on the business relating to the safety of plant and equipment used on the distribution system. It requires that plant and equipment is designed and operated within the limits of its capability.

Discharge of this obligation is supported by this document in providing guidance on the application of appropriate overhead line ratings.

3.1.5 Requirements of Northern Powergrid's Distribution Licence

Additional external business drivers relating to the development of the distribution system are the Distribution licenses applicable to Northern Powergrid Northeast and Northern Powergrid Yorkshire. Standard License condition 20 (Compliance with core industry documents) requires the licensee to comply with some of the core industry documents relevant to the design of distribution systems:

- Standard Licence Condition 20.1 requires the licensee to comply with the Grid Code;
- Standard Licence Condition 20.2 requires the licensee to at all times have in force, implement, and comply with the Distribution Code;
- Standard Licence Condition 20.3 requires the licensee to be a party to and comply with the Connection and Use of System Code (CUSC). The Connection and Use of System Code (CUSC) defines the contractual framework for connection to and use of the Great Britain's high voltage transmission system; and
- Standard Licence Condition 20.3 requires the licensee to be a party to and comply with the Distribution Connection and Use of System Agreement (DCUSA). The DCUSA is a multi-party contract between the DNOs, Suppliers and Generators that deals with the use of distribution system to transport electricity.
- Standard Licence Condition 24 (Distribution System planning standard and quality of performance reporting) includes requirements relating to system planning
- Standard Licence Condition 24.1 requires that the distribution system is planned and developed to a standard of security not less than that laid down in Engineering Recommendation P2/6 Security of Supply. This Code of Practice requires that voltage at a customer's Point of Supply is maintained within statutory limits in the secured events as defined in Engineering Recommendation P2/6.

3.1.6 Distribution Code

As a distribution licence holder, Northern Powergrid is required to hold, maintain and comply with the Distribution Code of Licensed Distribution Network Operators of Great Britain. The Distribution Code covers all material technical aspects relating to connections to and the operation and use of the distribution systems of the Distribution Network Operators. The Distribution Code is prepared by the Distribution Code Review Panel and is specifically designed to:

- permit the development, maintenance and operation of an efficient co-ordinated and economic system for the distribution of electricity;
- facilitate competition in the generation and supply of electricity; and
- efficiently discharge the obligations imposed upon DNOs by the distribution licence and comply with the Regulation (where Regulation has the meaning defined in the distribution licence) and any relevant legally binding decision of the European Commission and/or Agency for the Co-operation of Energy Regulators. This objective is particularly relevant given the introduction of a suite of European Network Codes which will place additional obligations on Generators and DNOs.

3.2 Key Requirements

The general objective in operating and developing the distribution system is to develop a simple and robust system having minimum overall cost, taking into account the initial capital investment, system losses and the maintainability and operability over the life of the asset.

This Code of Practice helps to ensure that the distribution system is operated and developed to:

- prevent danger to members of the public and Northern Powergrid staff and our sub-contractors;
- discharge the obligation under section 9 of the Act, and specifically to have due regard to future requirements and network performance;
- ensure the overhead line network has an appropriate capacity to supply our customers under normal and outage conditions; and
- satisfy all other relevant obligations.

3.3 Background

The overhead line current ratings in this code of practice are based on guidance given in Engineering Recommendation P27[4] and ACE Report No. 104[5] [6]. Both documents use a probabilistic approach which takes the pragmatic view that exceeding the overhead line conductor design temperature, and hence possibly infringing ground clearances, for a very small period of time (equivalent to about 6 minutes per year) is an acceptable risk. The probability of the design temperature of an overhead line being exceeded is based on the probability of different weather conditions coinciding with different circuit loadings[7].

As part of the CLNR project[8], real time direct measurements of actual conductor temperature and the environmental factors that affect it were captured and evaluated. This analysis confirmed that the ratings

[4] Engineering Recommendation P27, "*Current Rating Guide for High Voltage Overhead Lines Operating in the UK Distribution System*".

[5] British Electricity Board's ACE Report No. 104 (1986), "*Report on the Derivation of Overhead Line Ratings Applicable to High Voltage Distribution Systems*". The ratings given in ACE Report No. 104 are based on the recommendations given in the Central Electricity Generating Board's (CEGB's) Central Electricity Research Laboratory (CERL) Report RD/L/N 129/79, "*A Statistical Approach to the Thermal Rating of Zebra Conductor Based on Real Weather Observations*". CERL report RD/L/N 129/79 details measurements taken on overhead line conductor operating in varying environments, taking into account the temperature effects on a continuously loaded conductor by the interaction of sun, wind and ambient temperature.

[6] An active NIA project (NIA_WPD_0087) in which all DNOs are participating, aims to provide an informed revision of both ENA ACE 104 and ENA ER P27. The project, which commenced in 2015, is expected to end in the summer of 2018. Following the project completion, this policy will be updated accordingly.

[7] CLNR L-164 Lessons Learned Report – Real Time Thermal Rating.

[8] CLNR Developing the Smarter Grid- Optimal solutions for smarter network business (Chapter 7).

stated in the aforementioned documents are still valid and hence no fundamental change to the way ratings are calculated is required.

The rating of an overhead line conductor depends on the following factors:

- The system topology and the operational flexibility to reduce the load on the circuit, as this will influence the 'percentage excursion time' and the probability of 'exceedance';
- Weather conditions;
- The overhead line construction;
  - Conductor design temperature and other thermal limitations;
  - Conductor fitting; and
  - Overhead line design specifications.

3.3.1 Percentage Excursion Time and Exceedance

Percentage excursion time and exceedance are two terms that are often used interchangeably to describe the basis of overhead line ratings.

The probabilistic approach mentioned above provides a statistically based rating related to a predicted excursion in conductor design temperature where an excursion is the percentage of time in any particular season (with an assumed mix of ambient conditions) that a **continuously** loaded conductor is expected to exceed the conductor design temperature[9 10].

The probability, averaged over a year, that for a given load profile the overhead line design temperature is exceeded (i.e. there will be a temperature excursion) is called exceedance[11 12]. This probability is based on:

- System configuration;
- Fault rate;
- Load duration curve[13]; and
- Weather conditions;

The probabilities used for the rating calculations depend on the system configuration as this affects the load cycle (a single circuit will have a higher load than two parallel circuits sharing that same load), overhead lines fault rate as well as post fault load conditions.

The ratings of overhead line conductors in this code of practice are those that result in a statistically low level of risk of exceeding the conductor design temperature (equivalent to around 6 minutes a year).

3.3.2 System Configuration

The overhead line ratings applicable to the Northern Powergrid distribution system depend on the system configuration in which the overhead line is used i.e.:

- Single circuit 132kV and EHV systems and HV (open ring) systems; and

[9] The CERL report RD/L/N 129/79 describes an approach that can be applied to a range of conductors to provide statistically based ratings related to predicted 'percentage excursion times' in conductor design temperature.

[10] Engineering Recommendation P27, "*Current Rating Guide for High Voltage Overhead Lines Operating in the UK Distribution System*".

[11] STP Report Re-appraisal of ACE 104 Report – Project No: S2148_1.

[12] Historically, exceedance has been determined experimentally by counting the number of 6-minute periods in a year when the average conductor temperature was greater than the design temperature and then dividing this number by the total number of 6-minute periods in a year.

[13] Single overhead line circuits typically carry up to their rated current during normal operational conditions whereas multi-circuits typically only carry up to 50% load during normal operational conditions.

- Multi-circuit primary supply systems.

A diagram of the percentage time excursion applicable for overhead lines used in the different system topologies is shown in Appendix 2.

3.3.2.1 Single Circuit 132kV and EHV Systems and HV (open ring) Systems

Overhead lines used in 132kV and EHV single circuit radial systems and HV "open ring" systems (i.e. configured as radial feeders) are required to carry the maximum circuit load under normal operating conditions. The rating of 132kV and EHV overhead line circuits is therefore dependent only on the nature of the load and weather conditions and not on the fault rate. At HV however, overhead line systems experience a higher fault rate compared to EHV overhead lines, which in turn increases the risk of temperature excursion. The ratings for HV (open ring) systems are therefore depended on the nature of the load, the weather conditions and the fault rate.

A percentage excursion time of **0%** shall be adopted for the rating of these overhead lines[14].

3.3.2.2 Multi-circuit 132kV and EHV Systems

Overhead lines used in multi-circuit 132kV and EHV systems are assumed to supply maximum load only in the event of a circuit outage (e.g. a First Circuit Outage scenario). This arrangement is most commonly used for 132kV and EHV systems, such as duplicate transformer feeders to 132kV, 66kV and 33kV substations, but may also apply to an untapped HV system such as 11kV circuits providing a firm supply to a single demand or generation customer. Multi-circuit systems include 132kV, 66kV and 33kV ring circuits that are normally operated closed. The rating assessment assumes a low risk of circuit outage at a time of maximum load and the unlikely occurrence of high ambient temperature, low wind speed and high solar gain, all at the same time.

A percentage excursion time of **3%** shall be adopted for the rating of these overhead lines[15].

For intensive industrial, commercial and city centre networks, load variations are expected to be less frequent hence a 0.96 de-rating factor shall be applied to the 3% excursion time rating due to the higher risk of a fault occurring at a time of high load[16]. If in doubt, the lower rating shall be adopted.

Note:

A 10% excursion time has been historically adopted for specific circuits in accordance with legacy CEGB standard 993102, TPS 1/96 (Overhead Lines). The application of these ratings assume that following a fault, load on the remaining circuits can be reduced to its 0% excursion time rating within a relatively short period, for example by system switching, well within 24 hours, so that it remains 'likely' the overhead line conductor design temperature will not be exceeded.

A 10% excursion time can be used for 132kV overhead lines in a system with high configurational flexibility. Load management plans shall be prepared for all 132kV circuits where a 10% excursion time rating is applied to demonstrate that it is reasonably practical to reduce the load on the circuit to its 0% excursion time rating well within 24 hours of a fault occurring.

[14] The single circuit ratings were calculated based on the assumption that a line will always be carrying the full rated current. STP Project No. S2148_2 (Re-appraisal of ACE 104 – Stage 2) looked into revising P27 ratings by assuming a realistic variable load, rather than continuous full-rated load, based on typical Load Duration Curves (LDCs). This indicated that on average, typical single circuits can be rated about 5% higher than the ratings given in P27. However, the report suggested that this uprate would potentially provide mitigation against the fact that the original P27 ratings could actually be too high. NIA_WPD_0087 project will look into this in more detail with the aim to provide revised ratings.

[15] STP Project No. S2148_1 (Re-appraisal of ACE 104) examined the ACE 104 methodology relating to multi-circuit primaries to determine whether or not a higher figure and enhanced ratings could be achieved. According to the report, the 3% figure is based on two criteria: (a) the combined risk factor for normal supply conditions should not exceed $1x10^{-6}$ (1 in a million); which depends upon fault probability and the shape of the Load Duration Curve (LDC) and (b) the probability of conductor temperature exceeding its design temperature by 5° under post fault condition. The report concluded that the scope for raising the 3% figure was very limited due to the post fault criterion not being sufficiently objective to determine whether it could be relaxed. NIA Project (NIA_WPD_0087) will look into this in more detail with the aim to provide revised ratings.

[16] ACE Report No. 104.

3.3.3 Weather Conditions

The ratings in this document are based upon ambient weather conditions found typically in the United Kingdom as in Table 1[17]:

Parameter	Value
Wind Speed	0.5 m/s
Solar Radiation	nil
Seasonal Ambient Temperature	
Winter (Nov, Dec, Jan, Feb)	2°C
Spring (Mar, Apr)	9°C
Summer (May, Jun, Jul, Aug)	20°C
Autumn (Sep, Oct)	9°C

Table 1: Weather Conditions

3.3.4 Overhead Line Construction

A number of physical constructional factors influence the choice of the overhead line conductor ratings. The assignment of a rating to any particular overhead line circuit, or part of it, is based on the thermal limitations imposed by the overhead line conductor, the construction design specification that prevents any ground clearance violations, the conductor type and fittings.

3.3.4.1 Design Temperature

The rating of an overhead line is based on the conductor not exceeding a specified design temperature. The design temperature is specified to:

- Ensure that the conductor does not exceed the temperature at which the physical properties of the conductor begin to change. For copper and aluminium conductors, clear evidence of annealing begins to show at about 100°C. In some ACSR conductors the grease can start to migrate out from the conductor above a defined temperature.

- Provide a basis for assessing the overhead line clearance. Overhead lines are typically designed to give minimum statutory ground clearances at a conductor design temperature of 50˚C, 65˚C or 75˚C. Operating conductors at a higher temperature than the design temperature would increase the sag between poles or towers and could infringe statutory ground clearances.

The current passing through an overhead line conductor, together with the weather conditions, affect the temperature of the conductor which may cause excessive sag leading to ground clearance violations and/or flashover to adjacent structures.

3.3.4.2 Design Specifications for Overhead Lines

Legacy overhead line circuits were based upon the requirements of the former overhead line regulations El.C.53 (1947 Revise) - Electricity (Supply) Acts, 1882 to 1936; and The Electricity (Overhead Lines) Regulations 1970.

These regulations provided a basis for design as regards minimum ground clearance at a 'likely' maximum conductor design temperature. The 'likely' maximum conductor design temperature adopted across Northern Powergrid was 50°C (122°F).

The following table shows the different Northern Powergrid overhead line design specifications for overhead lines that are in use on the distribution system. The table shall be used to determine what design

[17] Engineering Recommendation P27, "*Current Rating Guide for High Voltage Overhead Lines Operating in the UK Distribution System*".

temperature shall be applied to establish the rating of a particular circuit (or part of) for a prescribed design specification.

The information in the table is independent of the type of conductor used. If there is any doubt of the rating to apply, a ground profile / line survey shall be carried out in conjunction with obtaining conductor samples to determine what limiting factors may exist that affect the rating. For initial planning purposes or where there is insufficient construction information available, a conservative approach shall be taken (i.e. assume a design temperature of 50°C).

Voltage	Licence Area	Design Specification	Construction Period	Design Temp to be assumed
132kV[18]	Northeast/ Yorkshire	Tower lines (various constructions) – previous CEGB ownership	1930 – 1975	50˚C
132kV	Northeast/ Yorkshire	Tower lines (various constructions) – previous	1975 – Present	75˚C
66/132kV	Northeast	NSP/004/046 (OHL9) (AP1 Style wood Pole lines)	2000- 2005	75˚C
33/66kV	Northeast/ Yorkshire	Tower & Riley & Neate Mast lines (various constructions)	1930 – 1980	50˚C
33/66kV	Yorkshire	Woodhouse Steel Masts	Circa 1930/40	50˚C
66kV	Northeast	Merz & Mclelland "A" and Portal Lines	1930 – 1975	50˚C
66kV	Northeast	OHL4/85 Single & Portal Lines	1985 – 2000	75˚C
33kV	Northeast/ Yorkshire	EATS 43-20 (heavy construction[19])	1968 – 1989	50˚C
33kV	Northeast	EATS 43-40 (at 33kV only)	1989 – Present	75˚C
33kV	Yorkshire	EATS 43-40 (at 33kV only)	1989 – 2005	65˚C
33/66kV	Yorkshire	CE/C/13 (heavy construction)	Circa 1940/50/60s	50˚C
33/66kV	Yorkshire	CE/C/20	Circa 1940/50/60s	50˚C
33/66kV	Yorkshire	CE/C/32	Circa 1940/50/60s	50˚C
33/66kV	Yorkshire	CE/C/35	Circa 1940/50/60s	50˚C
33/66kV	Yorkshire	CE/C/36 (heavy construction)	Circa 1940/50/60s	50˚C
33/66kV	Yorkshire	CE/C/37 (heavy construction)	Circa 1970s – 2002	65˚C

[18] CEGB 132kV tower lines were designed and constructed for a maximum operating temperature of 50°C until circa 1975. From this time new lines were generally designed and constructed to provide a maximum operating temperature of 75°C. When 132kV and 66kV tower lines have been refurbished, the opportunity has been taken to explore the potential for uprating the thermal rating of these lines to provide an increase in maximum operating temperature. In many cases a combination of conductor change and the replacement of the insulator fittings can offer the opportunity of a 65°C or 75°C design temperature. However unless records show an increased design temperature has been achieved, the line shall continue to be considered as having its original default 50°C design temperature unless a ground profile / line survey is carried out.

[19] This term refers to lines with a conductor cross sectional area of >=70mm^2 HDBC or 100mm^2 AAAC/ACSR or their imperial equivalents.

Voltage	Licence Area	Design Specification	Construction Period	Design Temp to be assumed
33/66kV	Yorkshire	CE/C/38	Circa 1940/50/60s	50˚C
33/66kV	Yorkshire	CE/OM/DC1(M)	Circa 1940/50/60s	65˚C
33/66kV	Yorkshire	CE/C/37(M1)	1998 – present	75˚C
HV	Northeast/ Yorkshire	BS1320 (light construction[20])	1953 – 1989	50˚C
HV	Northeast/ Yorkshire	EATS 43-10 (light construction)	1968 – 1989	50˚C
HV	Northeast/ Yorkshire	EATS 43-20 (heavy construction)	1968 – 1989	50˚C
HV	Northeast	Std Wishbone (light construction)	1930 – 1939	50˚C
HV	Northeast	Std Wishbone (heavy construction)	1930 – 1968	50˚C
HV	Northeast	NESCo Oak (light construction)	1939 – 1953	50˚C
HV	Yorkshire	CE/C/18 (tipped triangle)	1930 – 1953	50˚C
HV	Yorkshire	CE/C/31 (heavy construction)	1930 – 1989	50˚C
HV	Northeast	EATS 43-40 (light construction) – 11/20kV EATS 43-40 (heavy construction) – 11/20kV	1989 - present	50˚C 75˚C
HV	Yorkshire	EATS 43-40 (light construction) – 11kV EATS 43-40 (heavy construction) – 11kV	1989 – 2005	50˚C 65˚C

Table 2: Overhead Line Design Specification

3.3.4.3 New Build Overhead Line Design Specifications

All new build overhead line design specifications constructed in Northern Powergrid operating across all voltages (LV, HV, EHV, 132kV) are designed for operating at 75°C, with the exception of 50mm^2 bare or XLPE covered lines operating at 11 or 20kV which are designed for a maximum temperature of 50°C. The design standards that shall be used, are set out in the following Codes of Practice:

- Code of Practice for the Economic Development of the LV System, IMP/001/911;
- Code of Practice for the Economic Development of the HV System, IMP/001/912;
- Code of Practice for the Economic Development of the EHV System, IMP/001/913; and
- Code of Practice for the Economic Development of the 132kV System, IMP/001/914.

3.3.4.4 Conductor Type

The maximum conductor design temperature is dependent upon the type, age of manufacture and design of the conductor. These factors primarily relate to Aluminium Conductor Steel Reinforced (ACSR) conductor where the protective grease can migrate out of the conductor above a defined temperature, known as the ‘drop point’. The grease should have a sufficiently high ‘drop point’ to withstand the temperatures which can occur under post fault conditions and at the design temperature.

[20] This term refers to lines with a conductor cross sectional area of <=32mm^2 HDBC or 50mm^2 AAAC or their imperial equivalents.

Particular care should be taken when identifying the age and design of existing ACSR conductor when assessing the rating to be applied to a specific overhead line circuit (or part of). Only conductors manufactured and installed after circa 1975 are capable of operating at a design temperature of 75˚C due to the way in which the protective grease was applied to the inner and outer aluminium strands.

If there is any doubt of the age of an ACSR conductor in order to select a rating, the 'drop point' of the grease shall be determined by taking physical samples for detailed inspection.

3.3.4.5 Conductor Fittings

The integrity of joints and conductor connections (compression joints and conductor fittings) can also be a limiting factor when determining the rating of a specific overhead line circuit (or part of).

Overhead line compression and mechanical type connections installed after 1973 would have been tested in accordance with B.S. 3288: Part 1, 1973. This requires that the fitting resistance, using new materials made under laboratory conditions, is established as a benchmark. In practice, under field conditions, fittings may not be installed to such a high standard resulting in high initial resistances leading to deterioration and possible failure. The requirement under the B.S. is to ensure that in any future field tests, the fitting resistance must not be more than 30% greater than the benchmark value. Work has been carried out at Electricity Council Research Centre to determine the condition of such fittings after being in service for a period of time. The findings suggest that even existing continuous 50°C rating could result in a large number of joint failures[21].

Joint failure is more prevalent in the unlikely event of a temperature excursion. There may be design weaknesses or deterioration of components that may be overstressed by the higher temperatures both pre and post fault.

As an example, 'Tate and Noral' designs utilised at 132kV are usually unsuitable for 65˚C or 75˚C operation. When considering uprating the line or if in doubt of the integrity of the joints and connections, they shall be inspected with an infra-red camera to determine if any 'hot joints' are present. Where hot joints are found they shall be tested and remade in accordance with NSP/004/122, Guidance on the Electrical Resistance Testing of O/H line joints and terminations.

3.4 Overhead Line Ratings

3.4.1 General

A Generic Static Rating (GSR) is the current carrying capacity of an overhead line using standard assumptions based on the information provided in Section 3.3 and can be used for initial planning purposes for proposed overhead lines. These assumptions depend on the system configuration, fault rate, load duration curve and weather conditions and define the permitted percentage excursions times (0% or 3%). The current carrying capacity of an overhead line also depends on the overhead line design specification, summarised in Table 2, as this defines the temperature the circuit was designed to run at.

If the rating of a particular overhead line is critical, a Bespoke Static Rating (BSR) may be required. This involves a detailed assessment of the particular on-site conditions to establish a whether higher rating is possible on the basis that the circuit can operate at a higher temperature without infringing the statutory clearances.

Where the Bespoke Static Rating of an existing overhead line is insufficient for the assessed loading, the application of a Bespoke Dynamic Rating (BDR) may be considered. Application of a Bespoke Dynamic Rating requires real time monitoring (see section 3.4.5) and an associated control system[22] to regulate the flow of current. Application of a Bespoke Dynamic Rating should only be considered for existing overhead lines where it is more economic than developing the distribution system such that the application of a Generic

[21] ACE Report No. 104 (Appendix H, p.42).

[22] Such as an Active Network Management scheme to regulate circuit load in accordance with the Code of Practice for the Application of Active Network Management, IMP/001/016).

Static Rating or Bespoke Static Rating is sufficient. For all new overhead lines, the planned loading should be less than its Generic Static Rating or Bespoke Static Rating.

A summary of the different types of overhead line ratings are shown in Table 3.

Feature	Generic Static Rating (GSR)	Bespoke Static Rating (BSR)	Bespoke Dynamic Rating (BDR)
Application	New and existing overhead lines	New and existing overhead lines	Existing overhead lines only
Application voltage	LV, HV, EHV* & 132kV* (*initial planning stages)	HV, EHV, 132kV	HV[23], EHV, 132kV
Site survey	None	Initial measurement and/or site specific assessment	Frequent measurements through monitoring and periodic environmental assessment[24]
Monitoring of electrical parameters	None	None	Required
Control system	None	None	Required to regulate current flow
Technology readiness level	High	High	Medium

Table 3: A summary of the features of different overhead line ratings

3.4.2 Continuous Ratings

Unlike cables and transformers, due to their short thermal time constant[25], overhead lines have neither cyclic nor emergency ratings, they only have continuous ratings[26] that are applicable in the three seasons (summer, winter and spring/autumn).

Given the thermal time constants of different assets that could potentially be connected together (transformers and cables usually have a longer time constant), a holistic approach should be taken to determine the rating of the entire circuit and ensure no asset becomes overloaded[27]. For details on transformer and cable ratings as well as further information on the appropriate choice of overhead lines, refer to the following Codes of Practice (CoP):

[23] Although a Bespoke Dynamic Rating can be used at HV, it is not envisaged that it would be an economically viable option.

[24] A more frequent assessment should be considered for circuits with Bespoke Dynamic Ratings compared to those where a Generic or Bespoke Static Rating is applied.

[25] The time constant depends on the thermal conductivity of the insulation material. Thermal conductivity is the property of a material to conduct heat. Heat transfer occurs at a lower rate across materials of low thermal conductivity (such as soil and oil – applicable for cables and transformers) rather than across materials of high thermal conductivity (such as air – applicable for overhead lines).

[26] In reality, a very short period of overloading is acceptable during which load/generation can be controlled/curtailed or completely switched off. For example, assuming a typical overhead line time constant of 600 seconds (10 min) and a load of 80% of the overhead line's rating, the overhead line can be loaded to 120% of its rating for 520 seconds (8.6 min). This characteristic can be used in an automated post fault management scheme (such as an Active Network Management scheme) and would allow the overhead line to operate with a post-fault loading higher than its Generic Static Rating or Bespoke Static rating for a few minutes.

[27] Lessons learned from CLNR-L164 Report.

- Code of Practice for Underground Cable Rating and Parameters, IMP/001/013;
- Code of Practice for the Economic Development of the LV System, IMP/001/911;
- Code of Practice for the Economic Development of the HV System, IMP/001/912;
- Code of Practice for the Economic Development of the EHV System, IMP/001/913;
- Code of Practice for the Economic Development of the 132kv System, IMP/001/914; and
- Code of Practice for Transformer Ratings, IMP/001/918.

3.4.3 Generic Static Rating (GSR)

A Generic Static Rating is the current carrying capacity of an overhead line using standard assumptions based on the information provided in Section 3.3. The Generic Static Rating can be used for all existing overhead line circuits used on the distribution system where the system configuration and design specification are known[28]. A Generic Static Rating can also be used for initial planning purposes for proposed overhead lines, where the installation conditions are not yet known or where the assessed loading[29] is significantly lower than the Generic Static Rating.

The Generic Static Ratings for overhead lines can be found in Appendix 1. Overhead line ratings can also be found on the Grid under "Ratings" in the Asset Management Published Documents directory.

The ratings quoted in Appendix 1 of this document are the Generic Static Rating and are derived from a variety of sources including:

- ER P27 Current Rating Guide for High Voltage Overhead Lines Operating in the UK Distribution System;
- Legacy YEB Technical Manual Part 2, Section 3 – Technical Data;
- Legacy YEB Overhead Line Manual Part 7 – 132kV Overhead Lines;
- Legacy NEEB Engineering Instruction E707; and
- EA Technology OHRat tool.

As per Section 3.3, the ratings of overhead lines are dependent on the system, weather and their construction. The Generic Static Rating therefore can be determined by identifying the year the overhead line was built, hence the temperature the circuit was designed to run at (using Table 2) and the conductor type and size. The information can then be matched to the ratings in Appendix 1.

3.4.4 Bespoke Static Ratings (BSR)

Where the Generic Static Rating is insufficient for the assessed loading, a Bespoke Static Rating can be applied. A Bespoke Static Rating can be determined following an overhead line survey in accordance with the Code of Practice for the Survey of Overhead Line Routes, NSP/004/031. The survey will confirm the overhead line construction type, identify any construction and fitting restrictions and measure actual ground clearance to identify whether the overhead line circuit can operate at a higher temperature without violating statutory clearances[30].

To determine the feasibility of applying a Bespoke Static Rating, an initial desktop assessment can be performed using the *OHL Data Model*. The model, which contains static data on EHV wood poles and mast supports (excluding tower lines[31]), was developed based on the 2010 Poletec conditioning survey to identify any spans that are likely to have ground clearance infringements depending upon the design rating of the

[28] Table 2 on pages 12 and 13 gives an indication of the design specifications of overhead line depending on their construction type.

[29] i.e. existing loading or future calculated loading.

[30] Appropriate allowances would be needed as per current good practice.

[31] For tower lines, the model holds information only on their installation dates on a separate tab.

circuits[32]. Work was subsequently carried out to highlight any overhead lines that have the potential to be uprated and operate at higher design temperatures[33]. The model should only be used to provide an indication of the possibility of any ground clearance infringements occurring by running the overhead line at a higher temperature. If this initial desktop assessment suggests that a higher Bespoke Static Rating might be possible, an overhead line survey shall be carried out to confirm whether or not it is feasible. The OHL Clearance Model is accessible on The Grid under "Ratings" in the Asset Management Published Documents directory.

Note: The derivation of a Bespoke Static Rating, which is higher than the Generic Static Rating depends on various factors such as[34]:

- Ground clearance;
- Accuracy of erection of existing conductor;
- Present and future degree of creep;
- Stability of conductor grease;
- Basis of original sag chart; and
- Condition of conductor and conductor fittings.

Following a line survey and a confirmation that the overhead line can run at a higher temperature[35], a Bespoke Static Rating can be determined using ratings in Appendix 1 and, where the revised conductor design temperature is 65˚C or 75˚C, matching the conductor type to the new temperature. If the revised conductor design temperature is other than 65˚C or 75˚C, the rating will need to be assessed via modelling using OHRat [36]. OHRat is accessible on The Grid under "Ratings" in the Asset Management Published Documents directory.

Where a Bespoke Static Rating has been calculated, until an enduring process is established, a member of the Smart Grid Implementation team should be advised of the new rating, so that it can be recorded, along with the supporting analysis, in an appendix to a future version of this code of practice.

3.4.5 Bespoke Dynamic Rating (BDR)

Where the Bespoke Static Rating of an existing overhead line is insufficient for the assessed loading, the application of a Bespoke Dynamic Rating[37] may be considered. The application of a Bespoke Dynamic Rating requires real time monitoring and an associated control system[38] to regulate the current flows. Additional equipment will need to be installed or modified to measure real-time weather conditions (wind speed, wind direction and ambient temperature), actual line conductor temperature and current. The actual conductor sag can be calculated using the predetermined relationship between the conductor position/tension and

[32] Where analysis shows negative clearance value there is a high probability that if the line was to be operated at the stated design temperature it would not provide the required statutory clearances in that span. Conversely, if the value is positive, there is a high probability that if that line was to be operated at the stated design temperature, it would provide the required ground clearance. Overhead lines with potential infringement issues have been passed to the overhead line replacement team for further assessment.

[33] The model uses the observed ground clearance together with the time of year the survey took place to determine the likely ambient temperature at the time of the observation. The line span, construction and conductor types have been obtained from the existing databases. The assumptions that were made to develop the model can be found on the first tab of the model.

[34] Legacy YEB Technical Manual Part 2, Section 3 – Technical Data.

[35] The normal system studies should confirm that the duty on all assets in the scope of study are within their rating. Where the system studies suggests otherwise, there may be a need to assess their capability e.g. by carrying an overhead line assessment / survey of all the overhead lines within the scope of the study, to determine any remedial works required to accommodate the anticipated loading.

[36] A member of the Smart Grid Implementation team will be able to provide the password for accessing the model.

[37] BDR has been referred to as Real Time Thermal Rating (RTTR) during the CLNR project.

[38] Such as an Active Network Management scheme to regulate loadings.

temperature. The measurements and calculations can then be used to calculate the dynamic available capacity which will typically be greater than the static rating[39].

According to CLNR[40] trials, significant increases in thermal capacity can be achieved by applying Bespoke Static Ratings. Trials suggest that a Bespoke Dynamic Rating gives an increase in system capacity for over 80% of the period over the static ratings. However, the potential for overhead line capacity increases where they are in heavily sheltered sites is somewhat decreased[41]. It is worth mentioning that combinations of low wind speed and high ambient temperatures could result in Bespoke Dynamic Ratings lower than the Bespoke Static Rating for a small proportion of the time.

If a single measurement device is to be used on an overhead line circuit section, it should be installed at the location likely to have the lowest rating i.e. an area heavily sheltered from the wind. The location likely to have the lowest rating will need to be checked regularly (e.g. once a year) as tree growth or new buildings could determine the need for the measurement device to be relocated. The same site-dependent static parameters used in P27[42] are required in such a system to calculate the conductor operational temperature at frequent intervals. During the design stage, analysis is required to understand how a Bespoke Dynamic Rating can be deployed and the amount of controllable load or generation that is required as an integral part of the scheme[43]. The minimum controllable load required is the maximum difference between the demand or generation and the Bespoke Static Rating of the overhead line circuit. This may not occur when the rating is lowest or highest. CLNR trials on both HV and EHV networks demonstrated that real time rating systems can be designed, commissioned and operated successfully, however it is anticipated that a Bespoke Dynamic Rating will typically only be used on EHV and 132kV systems.

Application of a Bespoke Dynamic Rating should only be considered where it is more economic than developing the distribution system such that the application of a Generic Static Rating or Bespoke Dynamic Rating is sufficient. For all new overhead lines, the planned loading should be less than its Generic Static Rating or Bespoke Static Rating. It is envisaged that application of a Bespoke Dynamic Rating will only be used in a minority of cases. Enhanced overhead line ratings can be expected from the use of a Bespoke Dynamic Rating in specific instances such as wind farm connections, when peak generation will coincide with higher wind speeds, which may potentially cool down the conductor.

When considering applying Bespoke Dynamic Rating an assessment of the electrical losses shall be made in accordance with the Code of Practice for the Assessment of Asset Specific Losses, IMP/001/103.

As the application of a Bespoke Dynamic Rating is in its infancy, before considering a potential application, further guidance should be sought from the Head of Smart Grid Implementation.

3.5 Nominal Impedance Data

Appendix 3 shows typical impedance data for commonly used overhead lines on the Northern Powergrid system. Overhead line electrical parameters can also be found on the Grid under "Ratings" in the Asset Management Published Documents directory. The impedance data stated was derived from a variety of sources including:

- Legacy YEB Technical Manual Part 2, Section 3 – Technical Data;
- Power System Protection 1 – Principles and Components;
- Alstom – Protective Relays Application Guide;

[39] CLNR-L127.

[40] CLNR-L164.

[41] RTTR was implemented at HV and EHV networks, monitoring both sheltered and non-sheltered sites as part of CLNR trials.

[42] Conductor Resistance @ 20°C per unit length, Temperature coefficient of resistance for conductor, Conductor diameter, Span length, Conductor type, Design limits of the line (design temperature, minimum clearance).

[43] The Real Time Thermal Rating model used as part of CLNR to calculate real time ratings was based on CIGRE WR 22.12: 1992 which is based on the same experimental work as P27.

- ABB Pocket Book – Switchgear Manual (10th revised edition); and
- EA Technology OHRat tool.

It is intended that the data will be amended from time to time to include new overhead line designs. The data shown in Appendix 3 includes positive, negative and zero sequence components for resistance, inductive reactance, capacitance, susceptance and charging current for HV, EHV and 132kV overhead lines. The phase and earth resistance and inductive reactance are shown for LV overhead lines.

As with any conductor, an overhead line has resistance, inductance and capacitance, which influence the current flow through the conductor. The series impedance of an overhead line is complex and depends not only on the self-impedance of the conductor itself but also on the effects of currents in adjacent conductors and possibly the ground. Thus, the construction type and the spacing between conductors plays an important role.

For overhead lines, the positive sequence impedance (Z_1) and negative sequence impedance (Z_2) are the same; this value being equal to the normal impedance of the line. This is expected because the phase rotation of the currents does not make any difference in the line parameters. The zero sequence impedance (Z_0) depends upon the path taken by the zero sequence current, I_0. As this path is generally different from the path taken by I_1 and I_2, it is usually different and much greater.

3.5.1 Resistance

Resistance is a key parameter for voltage regulation and I^2R losses as they can limit the power transfer. The *Ohmic* resistance of a uniform conductor depends on its volumetric resistivity, ρ, at a defined temperature (usually measured at 20°C DC when tested in factory and carrying a DC current) and its cross-section area.

The distribution of alternating current across a conductor is not uniform, since the current density increases from the middle towards the outer layer, an effect known as “skin effect”. The increase in current density in the outer layers causes a greater I^2R loss for a given current, compared to a uniform distribution of current across the conductor, therefore being similar to that of an increase in *Ohmic* resistance.

The AC resistance of a conductor is higher than the measured DC resistance. It is therefore often used for the worst-case voltage regulation calculations; the DC resistance at 20°C is used for fault level studies, as this gives the worst-case scenario for fault level.

The positive and negative sequence resistances, R_1 and R_2, are sometimes available from manufacturer’s datasheets. However, where data was not available, the formulae in Appendix 4 were used to calculate resistances. Skin effect was not taken into consideration due to the almost negligible effect it has on the sizes of stranded conductors used across Northern Powergrid[44].

The zero sequence resistance values are not as readily available from manufacturer’s datasheets as they depend on the earth resistivity and the presence of an earth conductor. The formulae used to calculate R_{DC}, R_{AC}, R_1, R_2 and R_0 can be found in Appendix 4.

The DC and AC resistance values of the different conductors used across Northern Powergrid can be found in Appendix 3.

[44] According to p.105 of “The Transmission and Distribution of Electrical Energy - Third Edition, H. Cotton (1962)”, for solid copper conductors of diameter up to 0.5in the increase in effective resistance is negligible. For 0.75in the effective resistance increases by about 2.5% and for 1in by 8%. In aluminium conductors the effect is the same as in a copper conductor of equal conductivity. Since the resistivity of copper is 0.6 times that of aluminium, the increased resistance due to skin effect on an aluminium cable of α sq. in. cross section will be the same percentage as on a 0.6α sq. in. copper conductor. The skin effect is much smaller with stranded than with solid conductors and increases with permeability and cross-section of the conductor. Based on this, skin effect applies mostly to conductors above 175mm^2 but since the large conductors used across Northern Powergrid’s network are stranded, the increase in resistance would be much smaller than 8%, hence skin effect has been neglected in the calculations.

3.5.2 Reactance

The inductive reactance of an overhead line is derived from its self-inductance and the mutual inductance between the different phase conductors. For overhead lines, positive and negative sequence reactance values, X_1 and X_2, are equal. These values vary depending on the construction type (single phase, 3-phase single circuit, 3-phase double circuit) and spacing between conductors and hence they must be calculated separately. The set of formulae used to calculate X_1 and X_2 can be found in Appendix 4.

The zero sequence reactance value, X_0, depends upon a number of factors including the position and materials used for earth wires, construction type and the ground resistivity. Typical values for the ratio of zero to positive sequence reactance for single and double circuit overhead lines with and without earth wire can also be found in Appendix 4, Table 50.

It should be mentioned that in long overhead lines, asymmetrical conductor spacing results in significant differences in inductance for each phase which causes an unbalanced voltage drop and induced voltages to adjacent communication lines, even when the load currents are balanced. The problem can be overcome by interchanging the position of conductors at regular intervals along the route, a practice known as transposition, which results in each conductor having the same average inductance over a length of overhead line equivalent to the whole transposition cycle. This is achieved via special tower known as transposition towers. Appendix 3 shows the reactance values for both a normal and a transposed line of different conductor spacings and structures[45].

3.5.3 Capacitance

Capacitance is the ability of a body (conductor) to store electric charge and is caused by the potential difference between conductors of an overhead line. The flow of charge is a current and the current caused by the alternate charging and discharging of a line due to an alternating voltage is called the charging current of the line. Charging current affects the voltage drop and the power factor of the line since reactive current has to flow along the line to charge up the capacitance. Capacitance is therefore significant, especially on long high voltage overhead lines[46]. The capacitance values for the different types of overhead lines can be found in Appendix 3[47].

In a three-phase overhead line system, the capacitance of each conductor to neutral is considered instead of capacitance from conductor to conductor. Generally, the effect of earth on the capacitance is appreciable only when the distance between conductors is comparable to the height of the conductors above earth; this not generally the case. In this case the effect of earth on the line to neutral capacitance value is negligible. The formulae for calculating capacitance, susceptance (B) and the charging current can be found in Appendix 4.

Compared to cables, overhead lines have a much smaller capacitance due to the larger spacing between conductors. The capacitance for the various overhead line constructions is around 10nF/km.

[45] The tables in Appendix 3 show the reactance values for the structures used the most across Northern Powergrid.

[46] Elements of Power System Analysis – Second Edition, William Stevenson Jr. (1962) p.54.

[47] The tables in Appendix 3 show the capacitance values for the structures used the most across Northern Powergrid.

4. References

4.1 External Documentation

Reference	Title
BEB ACE report No.104	British Electricity Board's ACE Report No. 104 (1986), "Report on the Derivation of Overhead Line Ratings Applicable to High Voltage Distribution Systems".
CEGB TPS 1/96	Central Electricity Generating Board's (CEGB) standard 993102, TPS 1/96, "Current Ratings for Overhead Line Conductors".
CERL Report RD/L/N 129/79	CEGB Central Electricity Research Laboratory Report RD/L/N 129/79, "A Statistical Approach to the Thermal Rating of Zebra Conductor Based on Real Weather Observations".
CERL Report RD/L/N 29/76	CEGB Central Electricity Research Laboratory Report RD/L/N 29/76, "The Evaluation of Continuous and Overload ratings for Overhead Lines".
El.C.53	Overhead Line Regulations - made by the Electricity (Supply) Acts, 1882 to 1936.
ENATS 43-8	Electricity Networks Association Technical Specification 43-8, "Overhead Line Clearances".
ER P2/6	Engineering Recommendation P2/5 "Security of Supply".
ER P27	Engineering Recommendation P27, "Current Rating Guide for High Voltage Overhead Lines Operating in the UK Distribution System".
ESQC Regulations	The Electricity Supply, Quality and Continuity Regulations 2002.
Overhead Line Regulations 1970	The Electricity (Overhead Lines) Regulations 1970.
STP Project S2148_1	STP Report – Re-appraisal of ACE 104 Report
STP Project S2148_2	STP Report – Re-appraisal of ACE 104 Report (Stage 2)
The Act	The Electricity Act 1989 (as amended by the Utilities Act 2000 and the Energy Act 2004), the ESQCR 2002 (amendment No. 1521, 2006 and amendment No. 639, 2009), The Health and Safety at Work Act 1974
The Distribution Code	The Distribution Code covers all material technical aspects relating to connections to the operation and use of the Distribution Network Operators (DNOs)
The Grid Code	The Grid Code sets out the operating procedures and principles governing the relationship between NGET and all Users of the National Electricity Transmission System be they Generators. DC Converter owners, Suppliers or Non-Embedded Customers.

4.2 Internal Documentation

Reference	Title
IMP/001/013	Code of Practice for Underground Cable Rating and Parameters
IMP/001/016	Code of Practice for the Application of Active Network Management
IMP/001/103	Code of Practice for the Methodology of Assessing Losses
IMP/001/911	Code of Practice for the Economic Development of the LV system
IMP/001/912	Code of Practice for the Economic Development of the HV system
IMP/001/913	Code of Practice for the Economic Development of the EHV system
IMP/001/914	Code of Practice for the Economic Development of the 132kV system
IMP/001/918	Code of Practice for Transformer Ratings
NEEB Engineering Instruction E707	Legacy NEEB Engineering Instruction E707, Section 11 – System Planning, System Fault Levels
NSP/004/011	Code of Practice on Overhead Line Clearances
NSP/004/030	Code of Practice for the Construction and Refurbishment of 33-132kV tower lines
NSP/004/031	Code of Practice for the Survey of Overhead Line Routes
NSP/004/041	Code of Practice for the Construction of LV ABC Overhead Lines

Reference	Title
NSP/004/042	Specification for HV Wood Pole Lines up to and including 33kV
NSP/004/043	Specification for Overhead Services, Surface Wiring and Eaves Wall mains
NSP/004/044	Specification for HV Wood Pole Lines of Compact Covered Construction up to and including 33kV
NSP/004/045	Code of Practice for EHV Wood Pole Lines operating up to 132kV with span lengths up to 220m
NSP/004/105	Guidance on the selection, erection and sagging of O/H Conductors
NSP/004/122	Guidance on the Electrical Resistance Testing oh Overhead Line Joints and Terminations
YEB Overhead Line Manual	Legacy YEB Overhead Line Manual Part 7 – 132kV Overhead Lines
YEB Technical Manual Part 2	Legacy YEB Technical Manual Part 2, Section 3 – Technical Data

4.3 Amendments from Previous Version

Reference	Amendments
Whole Document	Doc approved by email Mark Callum 23/10/2023 Doc republished to grid - LB 29/01/2024

5. Definitions

Term	Definition
˚C	Degrees Centigrade
˚F	Degrees Fahrenheit
AAAC	All Aluminium Alloy Conductor
ACSR	Aluminium Conductor Steel reinforced
ANM	Active Network Management
B	Susceptance
B_0	Zero Sequence Susceptance
B_1	Positive Sequence Susceptance
B_2	Negative Sequence Susceptance
BDR	Bespoke Dynamic Ratings
BEB	British Electricity Board
BS	British Standard
BSR	Bespoke Static Ratings
C	Capacitance
C_0	Zero Sequence Capacitance
C_1	Positive Sequence Capacitance
C_2	Negative Sequence Capacitance
CC	Covered Conductor
CE/C/	Chief Engineer/Construction
CEGB	Central Electricity Generating Board
CERL	Central Electricity Research Laboratory
CLNR	Customer Led Network Revolution Project
C_N	Capacitance to neutral
DNO	Distribution Network Operator
EATS	Electricity Association Technical Specification (now ENATS)
EHV	Extra High Voltage
ENATS	Energy Networks Association Technical Specification (formally EATS)
ER	Engineering Recommendation
ESQCR	Electricity Supply, Quality and Continuity Regulations 2002
GMD	Geometric Mean Distance
GMR	Geometric Mean Radius
GSR	Generic Static Ratings
HDBC	Hard Drawn Bare Copper
Heavy Construction	This term refers to lines with conductor cross sectional areas of >=70mm^2 HDBC or 100mm^2 AAAC/ACSR or their imperial equivalents
HV	High Voltage
I_c	Charging Current
Light Construction	This term refers to lines with conductor cross sectional areas of <=32mm^2 HDBC or 50mm^2 AAAC or their imperial equivalents
LV	Low Voltage
NEEB	North Eastern Electricity Board
R	Resistance

Term	Definition
R_0	Zero Sequence Resistance
R_1	Positive Sequence Resistance
R_2	Negative Sequence Resistance
RTTR	Real-Time Thermal Rating
X	Reactance
X_0	Zero Sequence Reactance
X_1	Positive Sequence Reactance
X_2	Negative Sequence Reactance
XLPE	Crosslinked Polyethylene
YEB	Yorkshire Electricity Board
ε_0	Permittivity of free space (8.8542×10^{-12})

6. Authority for Issue

6.1 CDS Assurance

I sign to confirm that I have completed and checked this document and I am satisfied with its content and submit it for approval and authorisation.

		Date
Liz Beat	Governance Administrator	29/01/2024

6.2 Author

I sign to confirm that I have completed and checked this document and I am satisfied with its content and submit it for approval and authorisation.

Review Period - This document should be reviewed within the following time period.

Standard CDS review of 3 years?	Non Standard Review Period & Reason		
Yes	Period: n/a	Reason: n/a	
Should this document be displayed on the Northern Powergrid external website?			Yes
			Date
Paris Hadjiodysseos	Smart Grid Development Engineer		22/12/2017

6.3 Technical Assurance

I sign to confirm that I am satisfied with all aspects of the content and preparation of this document and submit it for approval and authorisation.

		Date
Ged Hammel	Senior Policy and Standards Engineer	28/12/2017
Alan Creighton	Senior Smart Grid Development Engineer	22/12/2017

6.4 Authorisation

Authorisation is granted for publication of this document.

		Date
Mark Callum	Smartgrid Development Manager	23/10/2023

Appendix 1 – Ratings

Appendix 1.1 – LV Overhead Lines Generic Static Ratings

	Conductors						0% Excursion					
Voltage (kV)	Material Type	in^2	mm^2	Code	No.	Design Temp (°C)	Summer		Autumn/Spring		Winter	
U							Amps	kVA	Amps	kVA	Amps	kVA
0.4	Copper	0.05	32	-	4 or 5	50	155	107	180	125	194	134
0.4	Copper	0.1	70	-	4 or 5	50	245	170	285	197	307	213
0.4	Copper	0.15	100	-	4 or 5	50	316	219	367	254	395	274
0.4	Copper	0.2	125	-	4 or 5	50	371	257	430	298	462	320
0.4	Al	0.05*	50	Ant	4 or 5	50	163	113	189	131	204	141
0.4	Al	0.1*	100	Wasp	4 or 5	50	258	179	299	207	322	223
0.4	Al	0.15*	150	Hornet	4 or 5	50	336	233	390	270	419	290

Table 4: LV Copper and Aluminium Open Wire overhead line Generic Static Ratings

	Conductors						0% Excursion			
Voltage (kV)	Material Type	in^2	mm^2	Code	No.	Design Temp (°C)	Pole Top		Under - eaves	
U							Amps	kVA	Amps	kVA
0.23	ABC	-	35	-	2	75	138	55	116	46
0.4	ABC	-	35	-	4	75	117	81	98	68
0.4	ABC	-	50	-	4	75	143	99	120	83
0.4	ABC	-	70	-	4	75	183	127	154	107
0.4	ABC	-	95	-	4	75	228	158	191	132
0.4	ABC	-	120	-	4 or 5	75	300	208	270	187

Table 5: LV ABC Overhead Line Generic Static Ratings[48]

*Copper Equivalent

[48] ABC Overhead Lines do not have seasonal ratings.

Appendix 1.2 – 11kV Overhead Line Generic Static Ratings

	Conductors						0% Excursion					
Voltage (kV)	Material Type	in^2	mm^2	Code	Bundled Conductors.	Design Temp (°C)	Summer		Autumn/Spring		Winter	
U							Amps	MVA	Amps	MVA	Amps	MVA
11	Cadmium Copper	0.017	13	-	1	50	78	1.5	90	1.7	97	1.8
11	Cadmium Copper	0.025	16	-	1	50	96	1.8	111	2.1	120	2.3
11	Cadmium Copper	0.04	26	-	1	50	131	2.5	152	2.9	164	3.1
11	Copper	0.025	16	-	1	50	99	1.9	115	2.2	124	2.4
11	Copper	0.05	32	-	1	50	155	3.0	180	3.4	194	3.7
11	Copper	0.058	37	-	1	50	167	3.2	193	3.7	208	4.0
11	Copper	0.075	48	-	1	50	192	3.7	223	4.2	240	4.6
11	Copper	0.1	70	-	1	50	245	4.7	285	5.4	307	5.8
11	Copper	0.1	70	-	1	65	296	5.6	328	6.2	347	6.6
11	Copper	0.1	70	-	1	75	325	6.2	353	6.7	370	7.0
11	Copper	0.15	100	-	1	50	316	6.0	367	7.0	395	7.5
11	Copper	0.15	100	-	1	65	382	7.3	423	8.1	446	8.5
11	Copper	0.15	100	-	1	75	419	8.0	455	8.7	477	9.1
11	Copper	0.2	125	-	1	50	364	6.9	422	8.0	454	8.6
11	Copper	0.2	125	-	1	65	440	8.4	487	9.3	514	9.8
11	Copper	0.2	125	-	1	75	483	9.2	525	10.0	549	10.5

Table 6: 11kV Cadmium and Hard Drawn Copper Overhead Line Generic Static Ratings

	Conductors						0% Excursion					
Voltage (kV)	Material Type	in^2	mm^2	Code	Bundled Conductors.	Design Temp (°C)	Summer		Autumn/Spring		Winter	
U							Amps	MVA	Amps	MVA	Amps	MVA
11	ASCR	0.05*	50	Rabbit	1	50	158	3.0	184	3.5	198	3.8
11	ASCR	0.1*	100	Dog	1	50	252	4.8	289	5.5	310	5.9
11	ASCR	0.1*	100	Dog	1	65	301	5.7	331	6.3	349	6.6
11	ASCR	0.1*	100	Dog	1	75	329	6.3	359	6.8	375	7.1
11	ASCR	0.15*	150	Dingo	1	50	337	6.4	391	7.4	421	8.0
11	ASCR	0.15*	150	Dingo	1	65	408	7.8	451	8.6	475	9.0
11	ASCR	0.15*	150	Dingo	1	75	447	8.5	486	9.3	508	9.7
11	ASCR	0.15*	150	Wolf	1	50	346	6.6	401	7.6	431	8.2
11	ASCR	0.15*	150	Wolf	1	65	418	8.0	462	8.8	487	9.3
11	ASCR	0.15*	150	Wolf	1	75	459	8.7	498	9.5	521	9.9
11	ASCR	0.175*	175	Lynx	1	50	382	7.3	442	8.4	476	9.1
11	ASCR	0.175*	175	Lynx	1	65	462	8.8	510	9.7	538	10.3
11	ASCR	0.175*	175	Lynx	1	75	507	9.7	550	10.5	575	11.0
11	ASCR	0.175*	175	Caracal	1	50	373	7.1	432	8.2	464	8.8
11	ASCR	0.175*	175	Caracal	1	65	450	8.6	498	9.5	525	10.0
11	ASCR	0.175*	175	Caracal	1	75	494	9.4	536	10.2	561	10.7

Table 7: 11kV Aluminium Conductor Steel Reinforced (ACSR) Overhead Line Generic Static Ratings

*Copper Equivalent

	Conductors						0% Excursion					
Voltage (kV)	Material Type	in^2	mm^2	Code	Bundled Conductors.	Design Temp (°C)	Summer		Autumn/Spring		Winter	
U							Amps	MVA	Amps	MVA	Amps	MVA
11	AAAC (AL3)	-	50	Hazel	1	50	165	3.1	191	3.6	206	3.9
11	AAAC (AL3)	-	100	Oak	1	65	314	6.0	347	6.6	366	7.0
11	AAAC (AL3)	-	100	Oak	1	75	345	6.6	375	7.1	392	7.5
11	AAAC (AL3)	-	175	Elm	1	65	458	8.7	506	9.6	534	10.2
11	AAAC (AL3)	-	175	Elm	1	75	504	9.6	547	10.4	572	10.9
11	AAAC (AL3)	-	200	Poplar	1	65	502	9.6	554	10.6	585	11.1
11	AAAC (AL3)	-	200	Poplar	1	75	551	10.5	598	11.4	626	11.9
11	AAAC (AL5)	-	50	Hazel	1	50	165	3.1	191	3.6	206	3.9
11	AAAC (AL5)	-	100	Oak	1	65	314	6.0	347	6.6	366	7.0
11	AAAC (AL5)	-	100	Oak	1	75	345	6.6	375	7.1	392	7.5
11	AAAC (AL5)	-	175	Elm	1	65	458	8.7	506	9.6	534	10.2
11	AAAC (AL5)	-	175	Elm	1	75	504	9.6	547	10.4	572	10.9
11	AAAC (AL5)	-	200	Poplar	1	65	502	9.6	554	10.6	585	11.1
11	AAAC (AL5)	-	200	Poplar	1	75	551	10.5	598	11.4	626	11.9

Table 8: 11kV AL3 and AL5 All Aluminium Alloy Conductor (AAAC) Overhead Line Generic Static Ratings

	Conductors						0% Excursion					
Voltage (kV)	Material Type	in^2	mm^2	Code	Bundled Conductors.	Design Temp (°C)	Summer		Autumn/Spring		Winter	
U							Amps	MVA	Amps	MVA	Amps	MVA
11	XLPE - CC (AL2)	-	50	-	1	50	148	2.8	172	3.3	185	3.5
11	XLPE - CC (AL2)	-	120	-	1	75	350	6.7	381	7.3	398	7.6
11	XLPE - CC (AL2)	-	185	-	1	75	461	8.8	500	9.5	523	10.0

Table 9: 11kV AL2 XLPE Covered Conductors (CC) Overhead Line Generic Static Ratings

Appendix 1.3 – 20kV Overhead Line Generic Static Ratings

	Conductors						0% Excursion					
Voltage (kV)	Material Type	in^2	mm^2	Code	Bundled Conductors.	Design Temp (°C)	Summer		Autumn/Spring		Winter	
U							Amps	MVA	Amps	MVA	Amps	MVA
20	Cadmium Copper	0.017	13	-	1	50	78	2.7	90	3.1	97	3.4
20	Cadmium Copper	0.025	16	-	1	50	96	3.3	111	3.8	120	4.2
20	Cadmium Copper	0.04	26	-	1	50	131	4.5	152	5.3	164	5.7
20	Copper	0.025	16	-	1	50	99	3.4	115	4.0	124	4.3
20	Copper	0.05	32	-	1	50	155	5.4	180	6.2	194	6.7
20	Copper	0.058	37	-	1	50	167	5.8	193	6.7	208	7.2
20	Copper	0.075	48	-	1	50	192	6.7	223	7.7	240	8.3
20	Copper	0.1	70	-	1	50	245	8.5	285	9.9	307	10.6
20	Copper	0.1	70	-	1	65	296	10.3	328	11.4	347	12.0
20	Copper	0.1	70	-	1	75	325	11.3	353	12.2	370	12.8
20	Copper	0.15	100	-	1	50	316	10.9	367	12.7	395	13.7
20	Copper	0.15	100	-	1	65	382	13.2	423	14.7	446	15.4
20	Copper	0.15	100	-	1	75	419	14.5	455	15.8	477	16.5
20	Copper	0.2	125	-	1	50	364	12.6	422	14.6	454	15.7
20	Copper	0.2	125	-	1	65	440	15.2	487	16.9	514	17.8
20	Copper	0.2	125	-	1	75	483	16.7	525	18.2	549	19.0

Table 10: 20kV Cadmium and Hard Drawn Copper Overhead Line Generic Static Ratings

	Conductors						0% Excursion					
Voltage (kV)	Material Type	in^2	mm^2	Code	Bundled Conductors.	Design Temp (°C)	Summer		Autumn/Spring		Winter	
U							Amps	MVA	Amps	MVA	Amps	MVA
20	ASCR	0.05*	50	Rabbit	1	50	158	5.5	184	6.4	198	6.9
20	ASCR	0.1*	100	Dog	1	50	252	8.7	289	10.0	310	10.7
20	ASCR	0.1*	100	Dog	1	65	301	10.4	331	11.5	349	12.1
20	ASCR	0.1*	100	Dog	1	75	329	11.4	359	12.4	375	13.0
20	ASCR	0.15*	150	Dingo	1	50	337	11.7	391	13.5	421	14.6
20	ASCR	0.15*	150	Dingo	1	65	408	14.1	451	15.6	475	16.5
20	ASCR	0.15*	150	Dingo	1	75	447	15.5	486	16.8	508	17.6
20	ASCR	0.15*	150	Wolf	1	50	346	12.0	401	13.9	431	14.9
20	ASCR	0.15*	150	Wolf	1	65	418	14.5	462	16.0	487	16.9
20	ASCR	0.15*	150	Wolf	1	75	459	15.9	498	17.3	521	18.0
20	ASCR	0.175*	175	Lynx	1	50	382	13.2	442	15.3	476	16.5
20	ASCR	0.175*	175	Lynx	1	65	462	16.0	510	17.7	538	18.6
20	ASCR	0.175*	175	Lynx	1	75	507	17.6	550	19.1	575	19.9
20	ASCR	0.175*	175	Caracal	1	50	373	12.9	432	15.0	464	16.1
20	ASCR	0.175*	175	Caracal	1	65	450	15.6	498	17.3	525	18.2
20	ASCR	0.175*	175	Caracal	1	75	494	17.1	536	18.6	561	19.4

Table 11: 20kV Aluminium Conductor Steel Reinforced (ACSR) Overhead Line Generic Static Ratings

*Copper Equivalent

	Conductors						0% Excursion					
Voltage (kV)	Material Type	in^2	mm^2	Code	Bundled Conductors.	Design Temp (°C)	Summer		Autumn/Spring		Winter	
U							Amps	MVA	Amps	MVA	Amps	MVA
20	AAAC (AL3)	-	50	Hazel	1	50	165	5.7	191	6.6	206	7.1
20	AAAC (AL3)	-	100	Oak	1	65	314	10.9	347	12.0	366	12.7
20	AAAC (AL3)	-	100	Oak	1	75	345	12.0	375	13.0	392	13.6
20	AAAC (AL3)	-	175	Elm	1	65	458	15.9	506	17.5	534	18.5
20	AAAC (AL3)	-	175	Elm	1	75	504	17.5	547	18.9	572	19.8
20	AAAC (AL3)	-	200	Poplar	1	65	502	17.4	554	19.2	585	20.3
20	AAAC (AL3)	-	200	Poplar	1	75	551	19.1	598	20.7	626	21.7
20	AAAC(AL5)	-	50	Hazel	1	50	165	5.7	191	6.6	206	7.1
20	AAAC(AL5)	-	100	Oak	1	65	314	10.9	347	12.0	366	12.7
20	AAAC(AL5)	-	100	Oak	1	75	345	12.0	375	13.0	392	13.6
20	AAAC(AL5)	-	175	Elm	1	65	458	15.9	506	17.5	534	18.5
20	AAAC(AL5)	-	175	Elm	1	75	504	17.5	547	18.9	572	19.8
20	AAAC(AL5)	-	200	Poplar	1	65	502	17.4	554	19.2	585	20.3
20	AAAC(AL5)	-	200	Poplar	1	75	551	19.1	598	20.7	626	21.7

Table 12: 20kV AL3 and AL5 All Aluminium Alloy Conductor (AAAC) Overhead Line Generic Static Ratings

	Conductors						0% Excursion					
Voltage (kV)	Material Type	in^2	mm^2	Code	Bundled Conductors.	Design Temp (°C)	Summer		Autumn/Spring		Winter	
U							Amps	MVA	Amps	MVA	Amps	MVA
20	XLPE - CC (AL2)	-	50	-	1	50	148	5.1	172	6.0	185	6.4
20	XLPE - CC (AL2)	-	120	-	1	75	350	12.1	381	13.2	398	13.8
20	XLPE - CC (AL2)	-	185	-	1	75	461	16.0	500	17.3	523	18.1

Table 13: 20kV AL2 XLPE Covered Conductors (CC) Overhead Line Generic Static Ratings

Appendix 1.4 – 33kV Overhead Line Generic Static Ratings

	Conductors						0% Excursion						3% Excursion					
Voltage (kV)	Material Type	in^2	mm^2	Code	Bundled Conductors.	Design Temp (°C)	Summer		Autumn/Spring		Winter		Summer		Autumn/Spring		Winter	
U							Amps	MVA	Amps	MVA	Amps	MVA	Amps	MVA	Amps	MVA	Amps	MVA
33	Copper	0.1	70	-	1	50	245	14.0	285	16.3	307	17.5	278	15.9	323	18.5	347	19.8
33	Copper	0.1	70	-	1	75	325	18.6	353	20.2	370	21.1	368	21.0	400	22.9	419	23.9
33	Copper	0.15	100	-	1	50	316	18.1	367	21.0	395	22.6	358	20.5	415	23.7	447	25.5
33	Copper	0.15	100	-	1	75	419	23.9	455	26.0	477	27.3	475	27.1	516	29.5	540	30.9
33	Copper	0.2	125	-	1	50	364	20.8	422	24.1	454	25.9	412	23.5	478	27.3	515	29.4
33	Copper	0.2	125	-	1	75	483	27.6	525	30.0	549	31.4	547	31.3	594	34.0	622	35.6

Table 14: 33kV Hard Drawn Copper Overhead Line Generic Static Ratings

	Conductors						0% Excursion						3% Excursion					
Voltage (kV)	Material Type	in^2	mm^2	Code	Bundled Conductors.	Design Temp (°C)	Summer		Autumn/Spring		Winter		Summer		Autumn/Spring		Winter	
U							Amps	MVA	Amps	MVA	Amps	MVA	Amps	MVA	Amps	MVA	Amps	MVA
33	ASCR	0.1*	100	Dog	1	50	252	14.4	289	16.5	310	17.7	285	16.3	327	18.7	351	20.1
33	ASCR	0.1*	100	Dog	1	75	329	18.8	359	20.5	375	21.4	372	21.3	406	23.2	425	24.3
33	ASCR	0.15*	150	Dingo	1	50	337	19.3	391	22.3	421	24.1	382	21.8	443	25.3	476	27.2
33	ASCR	0.15*	150	Dingo	1	75	447	25.5	485	27.7	508	29.0	507	29.0	550	31.4	575	32.9
33	ASCR	0.15*	150	Wolf	1	50	346	19.8	401	22.9	431	24.6	392	22.4	454	25.9	488	27.9
33	ASCR	0.15*	150	Wolf	1	75	459	26.2	498	28.5	521	29.8	520	29.7	564	32.2	590	33.7
33	ASCR	0.175*	175	Lynx	1	50	382	21.8	442	25.3	476	27.2	433	24.7	501	28.6	539	30.8
33	ASCR	0.175*	175	Lynx	1	65	462	26.4	510	29.2	538	30.8	523	29.9	578	33.0	609	34.8
33	ASCR	0.175*	175	Lynx	1	75	507	29.0	550	31.4	575	32.9	574	32.8	623	35.6	651	37.2
33	ASCR	0.175*	175	Caracal	1	50	373	21.3	432	24.7	464	26.5	422	24.1	489	28.0	526	30.1
33	ASCR	0.175*	175	Caracal	1	65	450	25.7	498	28.5	525	30.0	510	29.2	564	32.2	595	34.0

Table 15: 33kV Aluminium Conductor Steel Reinforced (ACSR) Overhead Line Generic Static Ratings

*Copper Equivalent

	Conductors						0% Excursion						3% Excursion					
Voltage (kV)	Material Type	in^2	mm^2	Code	Bundled Conductors.	Design Temp (°C)	Summer		Autumn/Spring		Winter		Summer		Autumn/Spring		Winter	
U							Amps	MVA	Amps	MVA	Amps	MVA	Amps	MVA	Amps	MVA	Amps	MVA
33	AAAC (AL3)	-	100	Oak	1	50	259	14.8	301	17.2	324	18.5	294	16.8	340	19.4	367	21.0
33	AAAC (AL3)	-	100	Oak	1	65	314	17.9	347	19.8	366	20.9	356	20.3	393	22.5	415	23.7
33	AAAC (AL3)	-	100	Oak	1	75	345	19.7	375	21.4	392	22.4	391	22.3	424	24.2	444	25.4
33	AAAC (AL3)	-	175	Elm	1	50	378	21.6	438	25.0	472	27.0	428	24.5	496	28.4	534	30.5
33	AAAC (AL3)	-	175	Elm	1	65	459	26.2	507	29.0	535	30.6	520	29.7	574	32.8	606	34.6
33	AAAC (AL3)	-	175	Elm	1	75	504	28.8	547	31.3	572	32.7	571	32.6	620	35.4	648	37.0
33	AAAC (AL3)	-	200	Poplar	1	50	414	23.7	479	27.4	515	29.4	468	26.7	543	31.0	584	33.4
33	AAAC (AL3)	-	200	Poplar	1	65	502	28.7	554	31.7	585	33.4	568	32.5	628	35.9	662	37.8
33	AAAC (AL3)	-	200	Poplar	1	75	551	31.5	598	34.2	626	35.8	624	35.7	678	38.8	709	40.5
33	AAAC (AL5)	-	100	Oak	1	50	265	15.1	307	17.5	330	18.9	300	17.1	348	19.9	374	21.4
33	AAAC (AL5)	-	100	Oak	1	65	321	18.3	355	20.3	374	21.4	363	20.7	402	23.0	424	24.2
33	AAAC (AL5)	-	100	Oak	1	75	352	20.1	382	21.8	400	22.9	399	22.8	433	24.7	453	25.9
33	AAAC (AL5)	-	175	Elm	1	50	386	22.1	447	25.5	481	27.5	436	24.9	506	28.9	545	31.2
33	AAAC (AL5)	-	175	Elm	1	65	468	26.7	517	29.6	546	31.2	530	30.3	585	33.4	618	35.3
33	AAAC (AL5)	-	175	Elm	1	75	514	29.4	558	31.9	583	33.3	582	33.3	632	36.1	661	37.8
33	AAAC (AL5)	-	200	Poplar	1	50	422	24.1	489	28.0	526	30.1	478	27.3	554	31.7	596	34.1
33	AAAC (AL5)	-	200	Poplar	1	65	512	29.3	566	32.4	597	34.1	580	33.2	641	36.6	676	38.6
33	AAAC (AL5)	-	200	Poplar	1	75	563	32.2	611	34.9	639	36.5	638	36.5	692	39.6	724	41.4

Table 16: 33kV AL3 and AL5 All Aluminium Alloy Conductor (AAAC) Overhead Line Generic Static Ratings

Appendix 1.5 – 66kV Overhead Line Generic Static Ratings

	Conductors						0% Excursion						3% Excursion					
Voltage (kV)	Material Type	in^2	mm^2	Code	Bundled Conductors	Design Temp (°C)	Summer		Autumn/Spring		Winter		Summer		Autumn/Spring		Winter	
U							Amps	MVA	Amps	MVA	Amps	MVA	Amps	MVA	Amps	MVA	Amps	MVA
66	Copper	0.1	70	-	1	50	245	28.0	285	32.6	307	35.1	278	31.8	323	36.9	347	39.7
66	Copper	0.1	70	-	1	75	325	37.2	353	40.4	370	42.3	368	42.1	400	45.7	419	47.9
66	Copper	0.15	100	-	1	50	316	36.1	367	42.0	395	45.2	358	40.9	415	47.4	447	51.1
66	Copper	0.15	100	-	1	75	419	47.9	455	52.0	477	54.5	475	54.3	516	59.0	540	61.7
66	Copper	0.2	125	-	1	50	364	41.6	422	48.2	454	51.9	412	47.1	478	54.6	515	58.9
66	Copper	0.2	125	-	1	75	483	55.2	525	60.0	549	62.8	547	62.5	594	67.9	622	71.1

Table 17: 66kV Hard Drawn Copper Overhead Line Generic Static Ratings

	Conductors						0% Excursion						3% Excursion					
Voltage (kV)	Material Type	in^2	mm^2	Code	Bundled Conductors	Design Temp (°C)	Summer		Autumn/Spring		Winter		Summer		Autumn/Spring		Winter	
U							Amps	MVA	Amps	MVA	Amps	MVA	Amps	MVA	Amps	MVA	Amps	MVA
66	ASCR	0.1*	100	Dog	1	50	252	28.8	289	33.0	310	35.4	285	32.6	327	37.4	351	40.1
66	ASCR	0.1*	100	Dog	1	75	329	37.6	359	41.0	375	42.9	372	42.5	406	46.4	425	48.6
66	ASCR	0.15*	150	Dingo	1	50	337	38.5	391	44.7	421	48.1	382	43.7	443	50.6	476	54.4
66	ASCR	0.15*	150	Dingo	1	75	447	51.1	485	55.4	508	58.1	507	58.0	550	62.9	575	65.7
66	ASCR	0.15*	150	Wolf	1	50	346	39.6	401	45.8	431	49.3	392	44.8	454	51.9	488	55.8
66	ASCR	0.15*	150	Wolf	1	75	459	52.5	498	56.9	521	59.6	520	59.4	564	64.5	590	67.4
66	ASCR	0.175*	175	Lynx	1	50	382	43.7	442	50.5	476	54.4	433	49.5	501	57.3	539	61.6
66	ASCR	0.175*	175	Lynx	1	65	462	52.8	510	58.3	538	61.5	523	59.8	578	66.1	609	69.6
66	ASCR	0.175*	175	Lynx	1	75	507	58.0	550	62.9	575	65.7	574	65.6	623	71.2	651	74.4
66	ASCR	0.175*	175	Caracal	1	50	373	42.6	432	49.4	464	53.0	422	48.2	489	55.9	526	60.1
66	ASCR	0.175*	175	Caracal	1	65	451	51.6	498	56.9	525	60.0	510	58.3	564	64.5	595	68.0

Table 18: 66 kV Aluminium Conductor Steel Reinforced (ACSR) Overhead Line Generic Static Ratings

	Conductors						0% Excursion						3% Excursion					
Voltage (kV)	Material Type	in²	mm²	Code	Bundled Conductors	Design Temp (°C)	Summer		Autumn/Spring		Winter		Summer		Autumn/Spring		Winter	
U							Amps	MVA	Amps	MVA	Amps	MVA	Amps	MVA	Amps	MVA	Amps	MVA
66	AAAC (AL3)	-	100	Oak	1	50	259	29.6	301	34.4	324	37.0	294	33.6	340	38.9	367	42.0
66	AAAC (AL3)	-	100	Oak	1	65	314	35.9	347	39.7	366	41.8	356	40.7	393	44.9	415	47.4
66	AAAC (AL3)	-	100	Oak	1	75	345	39.4	375	42.9	392	44.8	391	44.7	424	48.5	444	50.8
66	AAAC (AL3)	-	175	Elm	1	50	378	43.2	438	50.1	472	54.0	428	48.9	496	56.7	534	61.0
66	AAAC (AL3)	-	175	Elm	1	65	459	52.5	507	58.0	535	61.2	520	59.4	574	65.6	606	69.3
66	AAAC (AL3)	-	175	Elm	1	75	504	57.6	547	62.5	572	65.4	571	65.3	620	70.9	648	74.1
66	AAAC (AL3)	-	200	Poplar	1	50	414	47.3	479	54.8	515	58.9	468	53.5	543	62.1	584	66.8
66	AAAC (AL3)	-	200	Poplar	1	65	502	57.4	554	63.3	585	66.9	568	64.9	628	71.8	662	75.7
66	AAAC (AL3)	-	200	Poplar	1	75	551	63.0	598	68.4	626	71.6	624	71.3	678	77.5	709	81.0
66	AAAC (AL5)	-	100	Oak	1	50	265	30.3	307	35.1	330	37.7	300	34.3	348	39.8	374	42.8
66	AAAC (AL5)	-	100	Oak	1	65	321	36.7	355	40.6	374	42.8	363	41.5	402	46.0	424	48.5
66	AAAC (AL5)	-	100	Oak	1	75	352	40.2	382	43.7	400	45.7	399	45.6	433	49.5	453	51.8
66	AAAC (AL5)	-	175	Elm	1	50	386	44.1	447	51.1	481	55.0	436	49.8	506	57.8	545	62.3
66	AAAC (AL5)	-	175	Elm	1	65	468	53.5	517	59.1	546	62.4	530	60.6	585	66.9	618	70.6
66	AAAC (AL5)	-	175	Elm	1	75	514	58.8	558	63.8	583	66.6	582	66.5	632	72.2	661	75.6
66	AAAC (AL5)	-	200	Poplar	1	50	422	48.2	489	55.9	526	60.1	478	54.6	554	63.3	596	68.1
66	AAAC (AL5)	-	200	Poplar	1	65	512	58.5	566	64.7	597	68.2	580	66.3	641	73.3	676	77.3
66	AAAC (AL5)	-	200	Poplar	1	75	563	64.4	611	69.8	639	73.0	638	72.9	692	79.1	724	82.8

Table 19: 66kV AL3 and AL5 All Aluminium Alloy Conductor (AAAC) Overhead Line Generic Static Ratings

Appendix 1.6 – 132 Overhead Line Generic Static Ratings

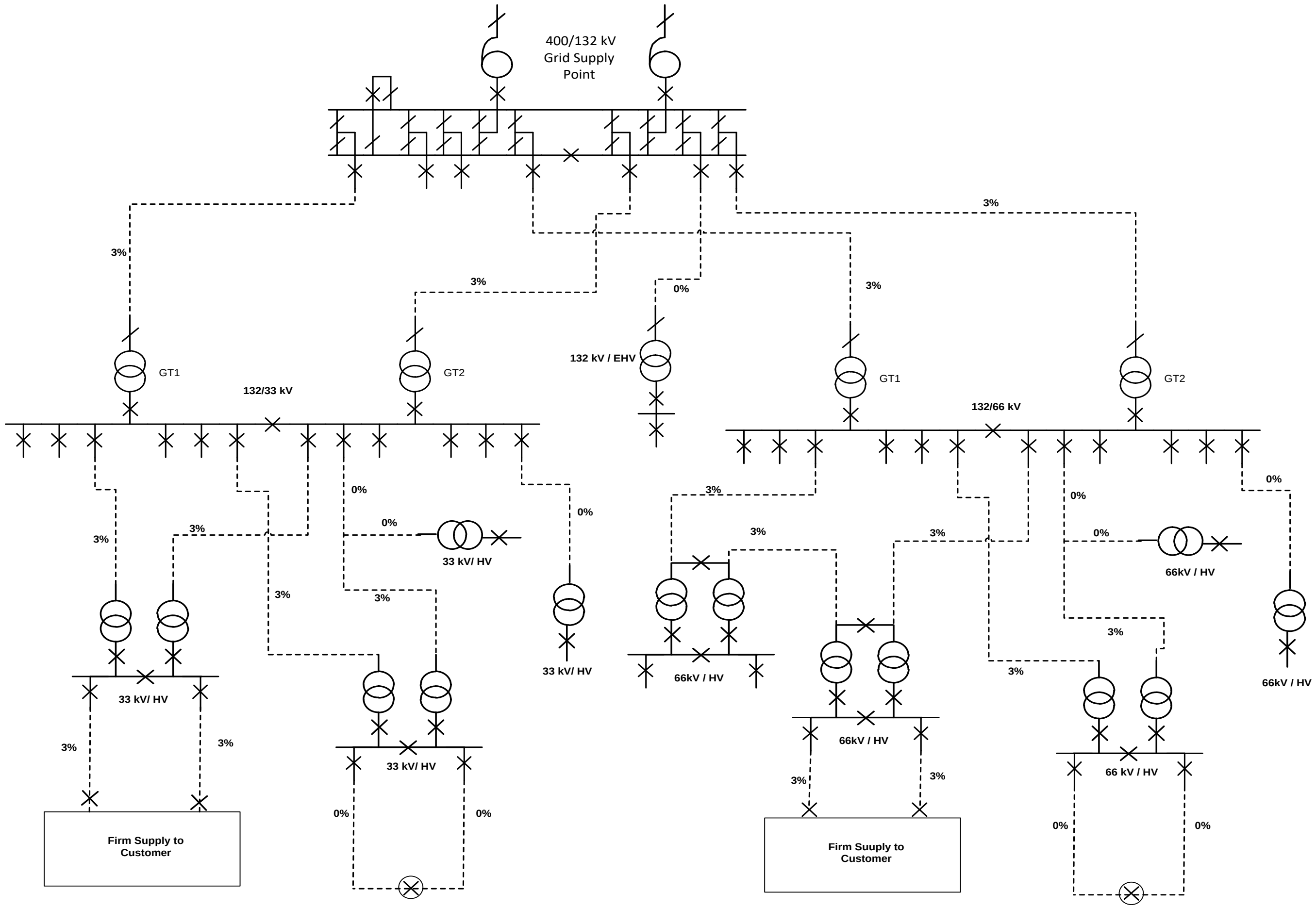
	Conductors						0% Excursion						3% Excursion					
Voltage (kV)	Material Type	strands	mm^2/in^2	Code	No.	Design Temp (°C)	Summer		Autumn/Spring		Winter		Summer		Autumn/Spring		Winter	
U							Amps	MVA	Amps	MVA	Amps	MVA	Amps	MVA	Amps	MVA	Amps	MVA
132	ACSR	30	150	Wolf	1	50	346	79.1	401	91.7	431	98.5	392	89.6	454	103.8	488	111.6
132	ACSR	30	150	Wolf	1	65	418	95.6	462	105.6	487	111.3	474	108.4	523	119.6	552	126.2
132	ACSR	30	150	Wolf	1	75	459	104.9	498	113.9	521	119.1	520	118.9	564	128.9	590	134.9
132	ACSR	30	175	Lynx	1	50	382	87.3	442	101.1	476	108.8	432	98.8	501	114.5	539	123.2
132	ACSR	30	175	Lynx	1	65	462	105.6	510	116.6	538	123.0	523	119.6	578	132.1	609	139.2
132	ACSR	30	175	Lynx	1	75	507	115.9	550	125.7	575	131.5	574	131.2	623	142.4	651	148.8
132	ASCR	30	175	Lynx	2	50	764	174.7	884	202.1	952	217.7	864	197.5	1002	229.1	1078	246.5
132	ASCR	30	175	Lynx	2	65	924	211.3	1020	233.2	1076	246.0	1046	239.1	1156	264.3	1218	278.5
132	ASCR	30	175	Lynx	2	75	1014	231.8	1100	251.5	1150	262.9	1148	262.5	1246	284.9	1302	297.7
132	ACSR	54	400	Zebra	1	50	658	150.4	760	173.8	817	186.8	745	170.3	861	196.9	925	211.5
132	ACSR	54	400	Zebra	1	65	796	182.0	878	200.7	924	211.3	902	206.2	994	227.3	1047	239.4
132	ACSR	54	400	Zebra	1	75	874	199.8	946	216.3	988	225.9	990	226.3	1072	245.1	1119	255.8

Table 20: 132kV Aluminium Conductor Steel Reinforced (ACSR) Overhead Line Generic Static Ratings

	Conductors						0% Excursion						3% Excursion					
Voltage (kV)	Material Type	strands	mm^2/in^2	Code	No.	Design Temp (°C)	Summer		Autumn/Spring		Winter		Summer		Autumn/Spring		Winter	
U							Amps	MVA	Amps	MVA	Amps	MVA	Amps	MVA	Amps	MVA	Amps	MVA
132	AAAC (AL3)	7	100	Oak	1	50	259	59.2	301	68.8	324	74.1	294	67.2	340	77.7	367	83.9
132	AAAC (AL3)	7	100	Oak	1	65	314	71.8	347	79.3	366	83.7	356	81.4	393	89.9	415	94.9
132	AAAC (AL3)	7	100	Oak	1	75	345	78.9	375	85.7	392	89.6	391	89.4	424	96.9	444	101.5
132	AAAC (AL3)	37	200	Poplar	1	50	414	94.7	479	109.5	515	117.7	468	107.0	543	124.1	584	133.5
132	AAAC (AL3)	37	200	Poplar	1	65	502	114.8	554	126.7	585	133.7	568	129.9	628	143.6	662	151.4
132	AAAC (AL3)	37	200	Poplar	1	75	551	126.0	598	136.7	626	143.1	625	142.9	678	155.0	708	161.9
132	AAAC (AL3)	31	300	Upas	1	50	545	124.6	631	144.3	679	155.2	618	141.3	715	163.5	769	175.8
132	AAAC (AL3)	31	300	Upas	1	65	662	151.4	731	167.1	771	176.3	750	171.5	828	189.3	873	199.6
132	AAAC (AL3)	31	300	Upas	1	75	728	166.4	790	180.6	825	188.6	825	188.6	895	204.6	935	213.8
132	AAAC (AL3)	61	500	Rubus	1	50	754	172.4	872	199.4	937	214.2	854	195.3	988	225.9	1062	242.8
132	AAAC (AL3)	61	500	Rubus	1	65	916	209.4	1011	231.1	1065	243.5	1038	237.3	1145	261.8	1207	276.0
132	AAAC (AL3)	61	500	Rubus	1	75	1009	230.7	1093	249.9	1142	261.1	1142	261.1	1238	283.0	1293	295.6
132	AAAC (AL3)	7	100	Oak	1	50	265	60.6	307	70.2	330	75.4	300	68.6	348	79.6	374	85.5
132	AAAC (AL3)	7	100	Oak	1	65	321	73.4	355	81.2	374	85.5	363	83.0	402	91.9	424	96.9
132	AAAC (AL3)	7	100	Oak	1	75	352	80.5	382	87.3	400	91.5	399	91.2	433	99.0	453	103.6
132	AAAC (AL5)	37	200	Poplar	1	50	422	96.5	489	111.8	526	120.3	478	109.3	554	126.7	596	136.3
132	AAAC (AL5)	37	200	Poplar	1	65	512	117.1	566	129.4	597	136.5	580	132.6	641	146.6	676	154.6
132	AAAC (AL5)	37	200	Poplar	1	75	563	128.7	611	139.7	639	146.1	638	145.9	692	158.2	724	165.5
132	AAAC (AL5)	31	300	Upas	1	50	557	127.3	645	147.5	693	158.4	631	144.3	730	166.9	785	179.5
132	AAAC (AL5)	31	300	Upas	1	65	676	154.6	747	170.8	787	179.9	766	175.1	846	193.4	891	203.7
132	AAAC (AL5)	31	300	Upas	1	75	744	170.1	806	184.3	843	192.7	842	192.5	913	208.7	955	218.3
132	AAAC (AL5)	61	500	Rubus	1	50	770	176.0	891	203.7	957	218.8	872	199.4	1009	230.7	1084	247.8
132	AAAC (AL5)	61	500	Rubus	1	65	936	214.0	1032	235.9	1088	248.8	1060	242.3	1169	267.3	1232	281.7
132	AAAC (AL5)	61	500	Rubus	1	75	1030	235.5	1116	255.2	1166	266.6	1166	266.6	1264	289.0	1320	301.8

Table 21: 132kV AL3 and AL5 All Aluminium Alloy Conductor (AAAC) Overhead Line Generic Static Ratings

Appendix 2 – Percentage excursion times



Appendix 3 – Resistance, Reactance and Capacitance

Appendix 3.1 – LV Overhead Line Resistance, reactance and capacitance (Ohmic)

	Conductors						Impedance (Ohm)				
Voltage (kV)	Material Type	in^2	mm^2	Code	No.	Design Temp (°C)	DC Resistance Ω/km (20°C)	AC Resistance at Design Temp Ω/km	Reactance Ω/km - 0.3m spacing	Resistance Ω/km	Reactance Ω/km
U							R_{dc}	R_1=R_2	X_1=X_2	R_0	X_0
0.4	Copper	0.05	32	-	4 or 5	50	0.541	0.602	0.306	1.081	0.612
0.4	Copper	0.1	70	-	4 or 5	50	0.259	0.289	0.292	0.518	0.584
0.4	Copper	0.15	100	-	4 or 5	50	0.176	0.196	0.277	0.353	0.555
0.4	Copper	0.2	125	-	4 or 5	50	0.144	0.160	0.265	0.287	0.531
0.4	Al	0.05*	50	Ant	4 or 5	50	0.542	0.607	0.296	1.084	0.593
0.4	Al	0.1*	100	Wasp	4 or 5	50	0.270	0.303	0.275	0.540	0.549
0.4	Al	0.15*	150	Hornet	4 or 5	50	0.183	0.205	0.259	0.365	0.517

Table 22: Copper and Aluminium Open Wire Overhead Line electrical parameters (Ohmic)

	Conductors						Impedance (Ohm)				
Voltage (kV)	Material Type	in^2	mm^2	Code	No.	Design Temp (°C)	DC Resistance Ω/km (20°C)	AC Resistance at Design Temp Ω/km	Reactance Ω/km - 0.3m spacing	Resistance Ω/km	Reactance Ω/km
U							R_{dc}	R_1=R_2	X_1=X_2	R_0	X_0
0.23	ABC	-	35	-	2	75	0.868	1.040	0.086	2.120	0.086
0.4	ABC	-	35	-	4	75	0.868	1.040	0.086	4.240	0.372
0.4	ABC	-	50	-	4	75	0.641	0.768	0.083	3.130	0.348
0.4	ABC	-	70	-	4	75	0.443	0.531	0.080	2.170	0.350
0.4	ABC	-	95	-	4	75	0.320	0.383	0.080	1.570	0.348
0.4	ABC	-	120	-	4 or 5	75	0.253	0.303	0.076	1.240	0.096

Table 23: ABC overhead line electrical parameters (Ohmic)

*Copper Equivalent

Appendix 3.2 – 11kV Overhead Line resistance, reactance and capacitance (100MVA Base)[49]

	Conductors						Positive & Negative Sequence (100MVA Base)				Zero Sequence (100MVA Base)		
Voltage (kV)	Material Type	in^2	mm^2	Code	Bundled Conductors.	Design Temp (°C)	DC Resistance Ω/km (20°C)	AC Resistance at Design Temp Ω/km	Reactance Ω/km	Susceptance Ω/km	Resistance Ω/km	Reactance Ω/km	Susceptance Ω/km
U							R_{dc}	R_1=R_2	X_1=X_2	B_1=B_2	R_0	X_0	B_0
11	Cadmium Copper	0.017	13	-	1	50	140.4	153.5	34.2	0.0003	152.6	119.8	0.0002
11	Cadmium Copper	0.025	16	-	1	50	96.0	104.9	33.8	0.0003	108.2	118.1	0.0002
11	Cadmium Copper	0.04	26	-	1	50	59.1	64.6	32.6	0.0004	71.3	114.0	0.0002

Table 24: 11kV Cadmium Copper Overhead Line Electrical Parameters (100MVA Base)

	Conductors						Positive & Negative Sequence (100MVA Base)				Zero Sequence (100MVA Base)		
Voltage (kV)	Material Type	in^2	mm^2	Code	Bundled Conductors.	Design Temp (°C)	DC Resistance Ω/km (20°C)	AC Resistance at Design Temp Ω/km	Reactance Ω/km	Susceptance Ω/km	Resistance Ω/km	Reactance Ω/km	Susceptance Ω/km
U							R_{dc}	R_1=R_2	X_1=X_2	B_1=B_2	R_0	X_0	B_0
11	Copper	0.025	16	-	1	50	89.50	99.73	33.26	0.0003	101.74	116.41	0.0002
11	Copper	0.05	32	-	1	50	44.71	49.82	31.50	0.0004	56.95	110.25	0.0002
11	Copper	0.058	37	-	1	50	39.11	43.59	31.87	0.0004	51.35	111.53	0.0002
11	Copper	0.075	48	-	1	50	30.25	33.71	31.96	0.0004	42.48	111.88	0.0002
11	Copper	0.1	70	-	1	50	21.40	23.85	30.40	0.0004	33.64	106.42	0.0002
11	Copper	0.1	70	-	1	65	21.40	25.07	30.40	0.0004	33.64	106.42	0.0002
11	Copper	0.1	70	-	1	75	21.40	25.89	30.40	0.0004	33.64	106.42	0.0002
11	Copper	0.15	100	-	1	50	14.64	16.31	29.48	0.0004	26.87	103.19	0.0002
11	Copper	0.15	100	-	1	65	14.64	17.15	30.08	0.0004	26.87	105.28	0.0002
11	Copper	0.15	100	-	1	75	14.64	17.70	30.08	0.0004	26.87	105.28	0.0002
11	Copper	0.2	125	-	1	50	11.71	13.05	28.52	0.0004	23.94	99.81	0.0002
11	Copper	0.2	125	-	1	65	11.71	13.72	28.52	0.0004	23.94	99.81	0.0002
11	Copper	0.2	125	-	1	75	11.71	14.16	28.52	0.0004	23.94	99.81	0.0002

Table 25: 11kV Copper Overhead Line Electrical Parameters (100MVA Base)

[49] Ohmic values can be found on the IMP/001/011 OHL Ratings and Impedance Datasheets.

	Conductors						Positive & Negative Sequence (100MVA Base)				Zero Sequence (100MVA Base)		
Voltage (kV)	Material Type	in^2	mm^2	Code	Bundled Conductors.	Design Temp (°C)	DC Resistance Ω/km (20°C)	AC Resistance at Design Temp Ω/km	Reactance Ω/km	Susceptance Ω/km	Resistance Ω/km	Reactance Ω/km	Susceptance Ω/km
U							R_{dc}	$R_1=R_2$	$X_1=X_2$	$B_1=B_2$	R_0	X_0	B_0
11	ASCR	0.05*	50	Rabbit	1	50	44.84	51.70	30.11	0.0004	57.08	105.39	0.0002
11	ASCR	0.1*	100	Dog	1	50	22.56	26.01	28.03	0.0004	34.80	98.10	0.0002
11	ASCR	0.1*	100	Dog	1	65	22.56	27.74	28.03	0.0004	34.80	98.10	0.0002
11	ASCR	0.1*	100	Dog	1	75	22.56	28.89	28.03	0.0004	34.80	98.10	0.0002
11	ASCR	0.15*	150	Dingo	1	50	15.04	17.34	27.68	0.0004	27.28	96.88	0.0002
11	ASCR	0.15*	150	Dingo	1	65	15.04	18.49	27.68	0.0004	27.28	96.88	0.0002
11	ASCR	0.15*	150	Dingo	1	75	15.04	19.26	27.68	0.0004	27.28	96.88	0.0002
11	ASCR	0.15*	150	Wolf	1	50	15.12	17.44	26.94	0.0004	27.36	94.31	0.0003
11	ASCR	0.15*	150	Wolf	1	65	15.12	18.59	26.94	0.0004	27.36	94.31	0.0003
11	ASCR	0.15*	150	Wolf	1	75	15.12	19.37	26.94	0.0004	27.36	94.31	0.0003
11	ASCR	0.175*	175	Lynx	1	50	13.02	15.02	26.55	0.0004	25.26	92.94	0.0003
11	ASCR	0.175*	175	Lynx	1	65	13.02	16.01	26.55	0.0004	25.26	92.94	0.0003
11	ASCR	0.175*	175	Lynx	1	75	13.02	16.68	26.55	0.0004	25.26	92.94	0.0003
11	ASCR	0.175*	175	Caracal	1	50	12.92	14.89	26.89	0.0004	25.15	94.11	0.0003
11	ASCR	0.175*	175	Caracal	1	65	12.92	15.88	26.89	0.0004	25.15	94.11	0.0003
11	ASCR	0.175*	175	Caracal	1	75	12.92	16.54	26.89	0.0004	25.15	94.11	0.0003

Table 26: 11kV Aluminium Conductor Steel Reinforced (ACSR) Overhead Line Electrical Parameters (100MVA Base)

*Copper Equivalent

	Conductors						Positive & Negative Sequence (100MVA Base)				Zero Sequence (100MVA Base)		
Voltage (kV)	Material Type	in^2	mm^2	Code	Bundled Conductors.	Design Temp (°C)	DC Resistance Ω/km (20°C)	AC Resistance at Design Temp Ω/km	Reactance Ω/km	Susceptance Ω/km	Resistance Ω/km	Reactance Ω/km	Susceptance Ω/km
U							R_{dc}	R_1=R_2	X_1=X_2	B_1=B_2	R_0	X_0	B_0
11	AAAC (AL3)	-	50	Hazel	1	50	45.44	50.35	30.76	0.0004	57.67	107.66	0.0002
11	AAAC (AL3)	-	100	Oak	1	65	22.88	26.59	28.96	0.0004	35.12	101.36	0.0002
11	AAAC (AL3)	-	100	Oak	1	75	22.88	27.42	28.96	0.0004	35.12	101.36	0.0002
11	AAAC (AL3)	-	175	Elm	1	65	12.96	15.06	27.21	0.0004	25.19	95.22	0.0003
11	AAAC (AL3)	-	175	Elm	1	75	12.96	15.52	27.21	0.0004	25.19	95.22	0.0003
11	AAAC (AL3)	-	200	Poplar	1	65	11.46	13.32	26.82	0.0004	23.70	93.85	0.0003
11	AAAC (AL3)	-	200	Poplar	1	75	11.46	13.73	26.82	0.0004	23.70	93.85	0.0003
11	AAAC (AL5)	-	50	Hazel	1	50	43.64	48.35	30.76	0.0004	55.87	107.66	0.0002
11	AAAC (AL5)	-	100	Oak	1	65	21.98	25.54	28.96	0.0004	34.22	101.36	0.0002
11	AAAC (AL5)	-	100	Oak	1	75	21.98	26.34	28.96	0.0004	34.22	101.36	0.0002
11	AAAC (AL5)	-	175	Elm	1	65	12.40	14.40	27.21	0.0004	24.63	95.22	0.0003
11	AAAC (AL5)	-	175	Elm	1	75	12.40	14.85	27.21	0.0004	24.63	95.22	0.0003
11	AAAC (AL5)	-	200	Poplar	1	65	10.99	12.77	26.82	0.0004	23.23	93.85	0.0003
11	AAAC (AL5)	-	200	Poplar	1	75	10.99	13.17	26.82	0.0004	23.23	93.85	0.0003

Table 27: 11kV AL3 and AL5 All Aluminium Alloy Conductor (AAAC) Overhead Line Electrical Parameters (100MVA Base)

	Conductors						Positive & Negative Sequence (100MVA Base)				Zero Sequence (100MVA Base)		
Voltage (kV)	Material Type	in^2	mm^2	Code	Bundled Conductors.	Design Temp (°C)	DC Resistance Ω/km (20°C)	AC Resistance at Design Temp Ω/km	Reactance Ω/km	Susceptance Ω/km	Resistance Ω/km	Reactance Ω/km	Susceptance Ω/km
U							R_{dc}	R_1=R_2	X_1=X_2	B_1=B_2	R_0	X_0	B_0
11	XLPE - CC (AL2)	-	50	-	1	50	59.50	65.93	25.26	0.0005	71.74	88.40	0.0003
11	XLPE - CC (AL2)	-	120	-	1	75	23.80	28.51	23.39	0.0005	36.04	81.85	0.0003
11	XLPE - CC (AL2)	-	185	-	1	75	15.54	18.61	22.51	0.0005	27.77	78.77	0.0003

Table 28: 11kV AL2 XLPE Covered Conductor Overhead Line Electrical Parameters (100MVA Base)

Appendix 3.3 – 20kV Overhead Line resistance, reactance and capacitance (100MVA Base)[50]

	Conductors						Positive & Negative Sequence (100MVA Base)				Zero Sequence (100MVA Base)		
Voltage (kV)	Material Type	in^2	mm^2	Code	Bundled Conductors.	Design Temp (°C)	DC Resistance Ω/km (20°C)	AC Resistance at Design Temp Ω/km	Reactance Ω/km	Susceptance Ω/km	Resistance Ω/km	Reactance Ω/km	Susceptance Ω/km
U							R_{dc}	$R_1=R_2$	$X_1=X_2$	$B_1=B_2$	R_0	X_0	B_0
20	Cadmium Copper	0.017	13	-	1	50	42.48	46.43	10.35	0.0011	46.18	36.23	0.0007
20	Cadmium Copper	0.025	16	-	1	50	29.03	31.72	10.21	0.0011	32.73	35.74	0.0007
20	Cadmium Copper	0.04	26	-	1	50	17.88	19.54	9.85	0.0012	21.58	34.47	0.0007

Table 29: 20kV Cadmium Copper Overhead Line Electrical Parameters (100MVA Base)

	Conductors						Positive & Negative Sequence (100MVA Base)				Zero Sequence (100MVA Base)		
Voltage (kV)	Material Type	in^2	mm^2	Code	Bundled Conductors.	Design Temp (°C)	DC Resistance Ω/km (20°C)	AC Resistance at Design Temp Ω/km	Reactance Ω/km	Susceptance Ω/km	Resistance Ω/km	Reactance Ω/km	Susceptance Ω/km
U							R_{dc}	$R_1=R_2$	$X_1=X_2$	$B_1=B_2$	R_0	X_0	B_0
20	Copper	0.025	16	-	1	50	27.08	30.17	10.06	0.0011	30.78	35.21	0.0007
20	Copper	0.05	32	-	1	50	13.53	15.07	9.53	0.0012	17.23	33.35	0.0007
20	Copper	0.058	37	-	1	50	11.97	13.33	9.64	0.0012	15.67	33.74	0.0007
20	Copper	0.075	48	-	1	50	9.22	10.28	9.68	0.0012	12.93	33.86	0.0007
20	Copper	0.1	70	-	1	50	6.48	7.22	9.20	0.0013	10.18	32.19	0.0008
20	Copper	0.1	70	-	1	65	6.48	7.59	9.20	0.0013	10.18	32.19	0.0008
20	Copper	0.1	70	-	1	75	6.48	7.83	9.20	0.0013	10.18	32.19	0.0008
20	Copper	0.15	100	-	1	50	4.43	4.93	8.92	0.0013	8.13	31.21	0.0008
20	Copper	0.15	100	-	1	65	4.43	5.19	9.10	0.0013	8.13	31.85	0.0008
20	Copper	0.15	100	-	1	75	4.43	5.36	9.10	0.0013	8.13	31.85	0.0008
20	Copper	0.2	125	-	1	50	3.54	3.95	8.63	0.0013	7.24	30.19	0.0008
20	Copper	0.2	125	-	1	65	3.54	4.15	8.63	0.0013	7.24	30.19	0.0008
20	Copper	0.2	125	-	1	75	3.54	4.28	8.63	0.0013	7.24	30.19	0.0008

Table 30: 20kV Copper Overhead Line Electrical Parameters (100MVA Base)

[50] Ohmic values can be found on the IMP/001/011 OHL Ratings and Impedance Datasheets.

	Conductors						Positive & Negative Sequence (100MVA Base)				Zero Sequence (100MVA Base)		
Voltage (kV)	Material Type	in^2	mm^2	Code	Bundled Conductors.	Design Temp (°C)	DC Resistance Ω/km (20°C)	AC Resistance at Design Temp Ω/km	Reactance Ω/km	Susceptance Ω/km	Resistance Ω/km	Reactance Ω/km	Susceptance Ω/km
U							R_{dc}	$R_1=R_2$	$X_1=X_2$	$B_1=B_2$	R_0	X_0	B_0
20	ASCR	0.05*	50	Rabbit	1	50	13.15	15.16	9.11	0.0013	16.85	31.88	0.0008
20	ASCR	0.1*	100	Dog	1	50	6.83	7.87	8.48	0.0013	10.53	29.67	0.0008
20	ASCR	0.1*	100	Dog	1	65	6.83	8.39	8.48	0.0013	10.53	29.67	0.0008
20	ASCR	0.1*	100	Dog	1	75	6.83	8.74	8.48	0.0013	10.53	29.67	0.0008
20	ASCR	0.15*	150	Dingo	1	50	4.55	5.25	8.37	0.0014	8.25	29.31	0.0008
20	ASCR	0.15*	150	Dingo	1	65	4.55	5.59	8.37	0.0014	8.25	29.31	0.0008
20	ASCR	0.15*	150	Dingo	1	75	4.55	5.83	8.37	0.0014	8.25	29.31	0.0008
20	ASCR	0.15*	150	Wolf	1	50	4.58	5.27	8.15	0.0014	8.28	28.53	0.0008
20	ASCR	0.15*	150	Wolf	1	65	4.58	5.62	8.15	0.0014	8.28	28.53	0.0008
20	ASCR	0.15*	150	Wolf	1	75	4.73	6.05	8.15	0.0014	8.43	28.53	0.0008
20	ASCR	0.175*	175	Lynx	1	50	3.94	4.54	8.03	0.0014	7.64	28.11	0.0009
20	ASCR	0.175*	175	Lynx	1	65	3.94	4.84	8.03	0.0014	7.64	28.11	0.0009
20	ASCR	0.175*	175	Lynx	1	75	3.94	5.05	8.03	0.0014	7.64	28.11	0.0009
20	ASCR	0.175*	175	Caracal	1	50	3.91	4.51	8.13	0.0014	7.61	28.47	0.0009
20	ASCR	0.175*	175	Caracal	1	65	3.91	4.80	8.13	0.0014	7.61	28.47	0.0009
20	ASCR	0.175*	175	Caracal	1	75	3.91	5.00	8.13	0.0014	7.61	28.47	0.0009

Table 31: 20kV Aluminium Conductor Steel Reinforced (ACSR) Overhead Line Electrical Parameters (100MVA Base)

*Copper Equivalent

	Conductors						Positive & Negative Sequence (100MVA Base)				Zero Sequence (100MVA Base)		
Voltage (kV)	Material Type	in^2	mm^2	Code	Bundled Conductors.	Design Temp (°C)	DC Resistance Ω/km (20°C)	AC Resistance at Design Temp Ω/km	Reactance Ω/km	Susceptance Ω/km	Resistance Ω/km	Reactance Ω/km	Susceptance Ω/km
U							R_{dc}	$R_1=R_2$	$X_1=X_2$	$B_1=B_2$	R_0	X_0	B_0
20	AAAC (AL3)	-	50	Hazel	1	50	13.75	15.23	9.30	0.0012	17.45	32.57	0.0007
20	AAAC (AL3)	-	100	Oak	1	65	6.92	8.04	8.76	0.0013	10.62	30.66	0.0008
20	AAAC (AL3)	-	100	Oak	1	75	6.92	8.29	8.76	0.0013	10.62	30.66	0.0008
20	AAAC (AL3)	-	175	Elm	1	65	3.92	4.56	8.23	0.0014	7.62	28.80	0.0008
20	AAAC (AL3)	-	175	Elm	1	75	3.92	4.70	8.23	0.0014	7.62	28.80	0.0008
20	AAAC (AL3)	-	200	Poplar	1	65	3.47	4.03	8.11	0.0014	7.17	28.39	0.0009
20	AAAC (AL3)	-	200	Poplar	1	75	3.47	4.15	8.11	0.0014	7.17	28.39	0.0009
20	AAAC(AL5)	-	50	Hazel	1	50	13.20	14.63	9.30	0.0012	16.90	32.57	0.0007
20	AAAC(AL5)	-	100	Oak	1	65	6.65	7.73	8.76	0.0013	10.35	30.66	0.0008
20	AAAC(AL5)	-	100	Oak	1	75	6.65	7.97	8.76	0.0013	10.35	30.66	0.0008
20	AAAC(AL5)	-	175	Elm	1	65	3.75	4.36	8.23	0.0014	7.45	28.80	0.0008
20	AAAC(AL5)	-	175	Elm	1	75	3.75	4.49	8.23	0.0014	7.45	28.80	0.0008
20	AAAC(AL5)	-	200	Poplar	1	65	3.33	3.86	8.11	0.0014	7.03	28.39	0.0009
20	AAAC(AL5)	-	200	Poplar	1	75	3.33	3.98	8.11	0.0014	7.03	28.39	0.0009

Table 32: 20kV AL3 and AL5 All Aluminium Alloy Conductor (AAAC) Overhead Line Electrical Parameters (100MVA Base)

	Conductors						Positive & Negative Sequence (100MVA Base)				Zero Sequence (100MVA Base)		
Voltage (kV)	Material Type	in^2	mm^2	Code	Bundled Conductors.	Design Temp (°C)	DC Resistance Ω/km (20°C)	AC Resistance at Design Temp Ω/km	Reactance Ω/km	Susceptance Ω/km	Resistance Ω/km	Reactance Ω/km	Susceptance Ω/km
U							R_{dc}	R_1=R_2	X_1=X_2	B_1=B_2	R_0	X_0	B_0
20	XLPE - CC (AL2)	-	50	-	1	50	18.00	19.94	7.86	0.0015	21.70	27.51	0.0009
20	XLPE - CC (AL2)	-	120	-	1	75	7.20	8.63	7.29	0.0016	10.90	25.53	0.0010
20	XLPE - CC (AL2)	-	185	-	1	75	4.70	5.63	7.03	0.0017	8.40	24.60	0.0010

Table 33: 20kV AL2 XLPE Covered Conductor Overhead Line Electrical Parameters (100MVA Base)

Appendix 3.4 – 33kV Overhead Line resistance, reactance and capacitance (100MVA Base)

	Conductors						Positive, Negative & Zero Sequence Resistance (100MVA base)							Positive, Negative & Zero Sequence Reactance and Capacitance (100MVA base) - 1.1m -1.2m spacing				Positive, Negative & Zero Sequence Reactance and Capacitance (100MVA base) - 2.0m - 2.4m spacing				Positive, Negative & Zero Sequence Reactance and Capacitance (100MVA base) - 2.7m - 3.1m spacing			
Voltage (kV)	Material Type	in^2	mm^2	Code	Bundled Conductors.	Design Temp (°C)	DC Resistance Ω/km (20°C)	Earth Wire Resistance	AC Resistance at Design Temp Ω/km	Resistance Ω/km - No EW (Portal Lines)	Resistance Ω/km - No EW (Double Circuit)	Resistance Ω/km - EW (Woodhouse Mast/ CE/C/37)	Resistance Ω/km - EW (Double Circuit)	Reactance Ω/km	Reactance Ω/km (No EW)	Susceptance µS/km	Susceptance µS/km	Reactance Ω/km	Reactance Ω/km (No EW)	Susceptance µS/km	Susceptance µS/km	Reactance Ω/km	Reactance Ω/km (No EW)	Susceptance µS/km	Susceptance µS/km
U							R_{dc}	RE_{dc}	$R_1=R_2$	R_0	R_0	R_0	R_0	$X_1=X_2$	X_o	$B_1=B_2$	B_0	$X_1=X_2$	X_o	$B_1=B_2$	B_0	$X_1=X_2$	X_o	$B_1=B_2$	B_0
33	Copper	0.1	70	-	1	50	2.38	2.38	2.65	3.74	5.10	3.52	4.66	3.39	11.88	0.0034	0.0021	3.79	13.28	0.0030	0.0018	3.95	13.84	0.0029	0.0017
33	Copper	0.1	70	-	1	75	2.38	2.38	2.88	3.74	5.10	3.52	4.66	3.39	11.88	0.0034	0.0021	3.79	13.28	0.0030	0.0018	3.95	13.84	0.0029	0.0017
33	Copper	0.15	100	-	1	50	1.63	2.38	1.81	2.98	4.34	2.77	3.91	3.27	11.44	0.0035	0.0021	3.67	12.84	0.0031	0.0019	3.83	13.40	0.0030	0.0018
33	Copper	0.15	100	-	1	75	1.63	2.38	1.97	2.98	4.34	2.77	3.91	3.27	11.44	0.0035	0.0021	3.67	12.84	0.0031	0.0019	3.83	13.40	0.0030	0.0018
33	Copper	0.2	125	-	1	50	1.30	2.38	1.45	2.66	4.02	2.45	3.59	3.18	11.14	0.0036	0.0022	3.58	12.54	0.0032	0.0019	3.74	13.09	0.0031	0.0018
33	Copper	0.2	125	-	1	75	1.30	2.38	1.58	2.66	4.02	2.45	3.59	3.18	11.14	0.0036	0.0022	3.58	12.54	0.0032	0.0019	3.74	13.09	0.0031	0.0018

Table 34: 33kV Copper Overhead Line Electrical Parameters (100MVA Base) – Flat Circuit Arrangement

	Conductors						Positive, Negative & Zero Sequence Resistance (100MVA base)							Positive, Negative & Zero Sequence Reactance and Capacitance (100MVA base) - DC Rutter Pole				Positive, Negative & Zero Sequence Reactance and Capacitance (100MVA base) - Double Circuit Mast Line (Normal)						Positive, Negative & Zero Sequence Reactance and Capacitance (100MVA base) - Double Circuit Mast Line (Transposed)						Positive, Negative & Zero Sequence Reactance and Capacitance (100MVA base) - Single Circuit Mast Line					
Voltage (kV)	Material Type	in^2	mm^2	Code	Bundled Conductors.	Design Temp (°C)	DC Resistance Ω/km (20°C)	Earth Wire Resistance	AC Resistance at Design Temp Ω/km	Resistance Ω/km - No EW (Portal Lines)	Resistance Ω/km - No EW (Double Circuit)	Resistance Ω/km - EW (Woodhouse Mast/ CE/C/37)	Resistance Ω/km - EW (Double Circuit)	Reactance Ω/km	Reactance Ω/km (No EW)	Susceptance µS/km	Susceptance µS/km	Reactance Ω/km	Reactance Ω/km (No EW)	Reactance Ω/km (EW)	Susceptance µS/km	Susceptance µS/km (NO EW)	Susceptance µS/km (EW)	Reactance Ω/km	Reactance Ω/km (No EW)	Reactance Ω/km (EW)	Susceptance µS/km	Susceptance µS/km (NO EW)	Susceptance µS/km (EW)	Reactance Ω/km	Reactance Ω/km (No EW)	Reactance Ω/km (EW)	Susceptance µS/km	Susceptance µS/km (NO EW)	Susceptance µS/km (EW)
U							R_{dc}	RE_{dc}	$R_1=R_2$	R_0	R_0	R_0	R_0	$X_1=X_2$	X_o	$B_1=B_2$	B_0	$X_1=X_2$	X_o	X_o	$B_1=B_2$	B_0	B_0	$X_1=X_2$	X_o	X_o	$B_1=B_2$	B_0	B_0	$X_1=X_2$	X_o	X_o	$B_1=B_2$	B_0	B_0
33	Copper	0.1	70	-	1	50	2.38	2.38	2.65	3.74	5.10	3.52	4.66	3.55	19.53	0.0034	0.0020	3.94	21.70	11.83	0.0033	0.0020	0.0023	3.66	20.12	10.98	0.0033	0.0020	0.0023	3.86	13.53	7.73	0.0030	0.0018	0.0021
33	Copper	0.1	70	-	1	75	2.38	2.38	2.88	3.74	5.10	3.52	4.66	3.55	19.53	0.0034	0.0020	3.94	21.70	11.83	0.0033	0.0020	0.0023	3.66	20.12	10.98	0.0033	0.0020	0.0023	3.86	13.53	7.73	0.0030	0.0018	0.0021
33	Copper	0.15	100	-	1	50	1.63	2.38	1.81	2.98	4.34	2.77	3.91	3.43	18.85	0.0035	0.0021	3.82	21.01	11.46	0.0034	0.0020	0.0024	3.53	19.44	10.60	0.0034	0.0020	0.0024	3.74	13.09	7.48	0.0031	0.0018	0.0021
33	Copper	0.15	100	-	1	75	1.63	2.38	1.97	2.98	4.34	2.77	3.91	3.43	18.85	0.0035	0.0021	3.82	21.01	11.46	0.0034	0.0020	0.0024	3.53	19.44	10.60	0.0034	0.0020	0.0024	3.74	13.09	7.48	0.0031	0.0018	0.0021
33	Copper	0.2	125	-	1	50	1.30	2.38	1.45	2.66	4.02	2.45	3.59	3.34	18.37	0.0036	0.0022	3.73	20.53	11.20	0.0035	0.0021	0.0024	3.45	18.96	10.34	0.0035	0.0021	0.0025	3.65	12.78	7.31	0.0031	0.0019	0.0022
33	Copper	0.2	125	-	1	75	1.30	2.38	1.58	2.66	4.02	2.45	3.59	3.34	18.37	0.0036	0.0022	3.73	20.53	11.20	0.0035	0.0021	0.0024	3.45	18.96	10.34	0.0035	0.0021	0.0025	3.65	12.78	7.31	0.0031	0.0019	0.0022

Table 35: 33kV Copper Overhead Line Electrical Parameters (100MVA Base) – Single and Double Circuit Mast Lines

	Conductors						Positive, Negative & Zero Sequence Resistance (100MVA base)							Positive, Negative & Zero Sequence Reactance and Capacitance (100MVA base) - 1.1m -1.2m spacing				Positive, Negative & Zero Sequence Reactance and Capacitance (100MVA base) - 2.0m - 2.4m spacing				Positive, Negative & Zero Sequence Reactance and Capacitance (100MVA base) - 2.7m - 3.1m spacing			
Voltage (kV)	Material Type	in^2	mm^2	Code	Bundled Conductors.	Design Temp (°C)	DC Resistance Ω/km (20°C)	Earth Wire Resistance	AC Resistance at Design Temp Ω/km	Resistance Ω/km - No EW (Portal Lines)	Resistance Ω/km - No EW (Double Circuit)	Resistance Ω/km - EW (Woodhouse Mast/ CE/C/37)	Resistance Ω/km - EW (Double Circuit)	Reactance Ω/km	Reactance Ω/km (No EW)	Susceptance µS/km	Susceptance µS/km	Reactance Ω/km	Reactance Ω/km (No EW)	Susceptance µS/km	Susceptance µS/km	Reactance Ω/km	Reactance Ω/km (No EW)	Susceptance µS/km	Susceptance µS/km
U							R_{dc}	RE_{dc}	$R_1=R_2$	R_0	R_0	R_0	R_0	$X_1=X_2$	X_o	$B_1=B_2$	B_0	$X_1=X_2$	X_o	$B_1=B_2$	B_0	$X_1=X_2$	X_o	$B_1=B_2$	B_0
33	ASCR	0.1*	100	Dog	1	50	2.51	3.62	2.89	3.87	5.23	3.72	4.92	3.13	10.96	0.0036	0.0022	3.53	12.36	0.0032	0.0019	3.69	12.92	0.0030	0.0018
33	ASCR	0.1*	100	Dog	1	75	2.51	3.62	3.21	3.87	5.23	3.72	4.92	3.13	10.96	0.0036	0.0022	3.53	12.36	0.0032	0.0019	3.69	12.92	0.0030	0.0018
33	ASCR	0.15*	150	Dingo	1	50	1.67	3.62	1.93	3.03	4.39	2.88	4.09	3.09	10.83	0.0037	0.0022	3.49	12.23	0.0033	0.0020	3.65	12.79	0.0031	0.0019
33	ASCR	0.15*	150	Dingo	1	75	1.67	3.62	2.14	3.03	4.39	2.88	4.09	3.09	10.83	0.0037	0.0022	3.49	12.23	0.0033	0.0020	3.65	12.79	0.0031	0.0019
33	ASCR	0.15*	150	Wolf	1	50	1.68	3.62	1.94	3.04	4.40	2.89	4.10	3.01	10.54	0.0038	0.0023	3.41	11.94	0.0033	0.0020	3.57	12.50	0.0032	0.0019
33	ASCR	0.15*	150	Wolf	1	75	1.68	3.62	2.15	3.04	4.40	2.89	4.10	3.01	10.54	0.0038	0.0023	3.41	11.94	0.0033	0.0020	3.57	12.50	0.0032	0.0019
33	ASCR	0.175*	175	Lynx	1	50	1.45	3.62	1.67	2.81	4.17	2.66	3.87	2.97	10.39	0.0038	0.0023	3.37	11.79	0.0034	0.0020	3.53	12.35	0.0032	0.0019
33	ASCR	0.175*	175	Lynx	1	65	1.45	3.62	1.78	2.81	4.17	2.66	3.87	2.97	10.39	0.0038	0.0023	3.37	11.79	0.0034	0.0020	3.53	12.35	0.0032	0.0019
33	ASCR	0.175*	175	Lynx	1	75	1.45	3.62	1.86	2.81	4.17	2.66	3.87	2.97	10.39	0.0038	0.0023	3.37	11.79	0.0034	0.0020	3.53	12.35	0.0032	0.0019
33	ASCR	0.175*	175	Caracal	1	50	1.43	3.62	1.65	2.79	4.15	2.64	3.85	3.01	10.52	0.0038	0.0023	3.41	11.92	0.0034	0.0020	3.56	12.48	0.0032	0.0019
33	ASCR	0.175*	175	Caracal	1	65	1.43	3.62	1.76	2.79	4.15	2.64	3.85	3.01	10.52	0.0038	0.0023	3.41	11.92	0.0034	0.0020	3.56	12.48	0.0032	0.0019

Table 36: 33kV Aluminium Conductor Steel Reinforced (ACSR) Overhead Line Electrical Parameters (100MVA Base) – Flat Circuit Arrangement

*Copper Equivalent

	Conductors						Positive, Negative & Zero Sequence Resistance (100MVA base)							Positive, Negative & Zero Sequence Reactance and Capacitance (100MVA base) - DC Rutter Pole				Positive, Negative & Zero Sequence Reactance and Capacitance (100MVA base) - Double Circuit Mast Line (Normal)						Positive, Negative & Zero Sequence Reactance and Capacitance (100MVA base) - Double Circuit Mast Line (Transposed)						Positive, Negative & Zero Sequence Reactance and Capacitance (100MVA base) - Single Circuit Mast Line					
Voltage (kV)	Material Type	in^2	mm^2	Code	Bundled Conductors.	Design Temp (°C)	DC Resistance Ω/km (20°C)	Earth Wire Resistance	AC Resistance at Design Temp Ω/km	Resistance Ω/km - No EW (Portal Lines)	Resistance Ω/km - No EW (Double Circuit)	Resistance Ω/km - EW (Woodhouse Mast/ CE/C/37)	Resistance Ω/km - EW (Double Circuit)	Reactance Ω/km	Reactance Ω/km (No EW)	Susceptance µS/km	Susceptance µS/km	Reactance Ω/km	Reactance Ω/km (No EW)	Reactance Ω/km (EW)	Susceptance µS/km	Susceptance µS/km (NO EW)	Susceptance µS/km (EW)	Reactance Ω/km	Reactance Ω/km (No EW)	Reactance Ω/km (EW)	Susceptance µS/km	Susceptance µS/km (NO EW)	Susceptance µS/km (EW)	Reactance Ω/km	Reactance Ω/km (No EW)	Reactance Ω/km (EW)	Susceptance µS/km	Susceptance µS/km (NO EW)	Susceptance µS/km (EW)
U							R_{dc}	RE_{dc}	$R_1=R_2$	R_0	R_0	R_0	R_0	$X_1=X_2$	X_o	$B_1=B_2$	B_0	$X_1=X_2$	X_o	X_o	$B_1=B_2$	B_0	B_0	$X_1=X_2$	X_o	X_o	$B_1=B_2$	B_0	B_0	$X_1=X_2$	X_o	X_o	$B_1=B_2$	B_0	B_0
33	ASCR	0.1*	100	Dog	1	50	2.51	3.62	2.89	3.87	5.23	3.72	4.92	3.29	18.09	0.0036	0.0021	3.68	20.26	18.42	0.0034	0.0021	0.0024	3.40	18.69	16.99	0.0035	0.0021	0.0024	3.60	12.61	12.61	0.0031	0.0019	0.0022
33	ASCR	0.1*	100	Dog	1	75	2.51	3.62	3.21	3.87	5.23	3.72	4.92	3.29	18.09	0.0036	0.0021	3.68	20.26	18.42	0.0034	0.0021	0.0024	3.40	18.69	16.99	0.0035	0.0021	0.0024	3.60	12.61	12.61	0.0031	0.0019	0.0022
33	ASCR	0.15*	150	Dingo	1	50	1.67	3.62	1.93	3.03	4.39	2.88	4.09	3.25	17.88	0.0037	0.0022	3.64	20.05	18.22	0.0035	0.0021	0.0025	3.36	18.47	16.80	0.0036	0.0022	0.0025	3.56	12.48	12.48	0.0032	0.0019	0.0022
33	ASCR	0.15*	150	Dingo	1	75	1.67	3.62	2.14	3.03	4.39	2.88	4.09	3.25	17.88	0.0037	0.0022	3.64	20.05	18.22	0.0035	0.0021	0.0025	3.36	18.47	16.80	0.0036	0.0022	0.0025	3.56	12.48	12.48	0.0032	0.0019	0.0022
33	ASCR	0.15*	150	Wolf	1	50	1.68	3.62	1.94	3.04	4.40	2.89	4.10	3.17	17.43	0.0037	0.0022	3.56	19.60	17.82	0.0036	0.0022	0.0025	3.28	18.03	16.39	0.0036	0.0022	0.0026	3.48	12.19	12.19	0.0033	0.0020	0.0023
33	ASCR	0.15*	150	Wolf	1	75	1.68	3.62	2.15	3.04	4.40	2.89	4.10	3.17	17.43	0.0037	0.0022	3.56	19.60	17.82	0.0036	0.0022	0.0025	3.28	18.03	16.39	0.0036	0.0022	0.0026	3.48	12.19	12.19	0.0033	0.0020	0.0023
33	ASCR	0.175*	175	Lynx	1	50	1.45	3.62	1.67	2.81	4.17	2.66	3.87	3.13	17.19	0.0038	0.0023	3.52	19.36	17.60	0.0036	0.0022	0.0025	3.23	17.79	16.17	0.0037	0.0022	0.0026	3.44	12.04	12.04	0.0033	0.0020	0.0023
33	ASCR	0.175*	175	Lynx	1	65	1.45	3.62	1.78	2.81	4.17	2.66	3.87	3.13	17.19	0.0038	0.0023	3.52	19.36	17.60	0.0036	0.0022	0.0025	3.23	17.79	16.17	0.0037	0.0022	0.0026	3.44	12.04	12.04	0.0033	0.0020	0.0023
33	ASCR	0.175*	175	Lynx	1	75	1.45	3.62	1.86	2.81	4.17	2.66	3.87	3.13	17.19	0.0038	0.0023	3.52	19.36	17.60	0.0036	0.0022	0.0025	3.23	17.79	16.17	0.0037	0.0022	0.0026	3.44	12.04	12.04	0.0033	0.0020	0.0023
33	ASCR	0.175*	175	Caracal	1	50	1.43	3.62	1.65	2.79	4.15	2.64	3.85	3.16	17.40	0.0038	0.0023	3.56	19.56	17.78	0.0036	0.0022	0.0025	3.27	17.99	16.35	0.0037	0.0022	0.0026	3.48	12.17	12.17	0.0033	0.0020	0.0023
33	ASCR	0.175*	175	Caracal	1	65	1.43	3.62	1.76	2.79	4.15	2.64	3.85	3.16	17.40	0.0038	0.0023	3.56	19.56	17.78	0.0036	0.0022	0.0025	3.27	17.99	16.35	0.0037	0.0022	0.0026	3.48	12.17	12.17	0.0033	0.0020	0.0023

Table 37: 33kV Aluminium Conductor Steel Reinforced (ACSR) Overhead Line Electrical Parameters (100MVA Base) – Single and Double Circuit Mast Lines

*Copper Equivalent

	Conductors						Positive, Negative & Zero Sequence Resistance (100MVA base)							Positive, Negative & Zero Sequence Reactance and Capacitance (100MVA base) - 1.1m -1.2m spacing				Positive, Negative & Zero Sequence Reactance and Capacitance (100MVA base) - 2.0m - 2.4m spacing				Positive, Negative & Zero Sequence Reactance and Capacitance (100MVA base) - 2.7m - 3.1m spacing			
Voltage (kV)	Material Type	in^2	mm^2	Code	Bundled Conductors.	Design Temp (°C)	DC Resistance Ω/km (20°C)	Earth Wire Resistance	AC Resistance at Design Temp Ω/km	Resistance Ω/km - No EW (Portal Lines)	Resistance Ω/km - No EW (Double Circuit)	Resistance Ω/km - EW (Woodhouse Mast/ CE/C/37)	Resistance Ω/km - EW (Double Circuit)	Reactance Ω/km	Reactance Ω/km (No EW)	Susceptance µS/km	Susceptance µS/km	Reactance Ω/km	Reactance Ω/km (No EW)	Susceptance µS/km	Susceptance µS/km	Reactance Ω/km	Reactance Ω/km (No EW)	Susceptance µS/km	Susceptance µS/km
U							R_{dc}	RE_{dc}	$R_1=R_2$	R_0	R_0	R_0	R_0	$X_1=X_2$	X_o	$B_1=B_2$	B_0	$X_1=X_2$	X_o	$B_1=B_2$	B_0	$X_1=X_2$	X_o	$B_1=B_2$	B_0
33	AAAC (AL3)	-	100	Oak	1	50	2.54	3.62	2.82	3.90	5.26	3.75	4.96	3.24	11.33	0.0036	0.0022	3.64	12.73	0.0032	0.0019	3.80	13.28	0.0030	0.0018
33	AAAC (AL3)	-	100	Oak	1	65	2.54	3.62	2.96	3.90	5.26	3.75	4.96	3.24	11.33	0.0036	0.0022	3.64	12.73	0.0032	0.0019	3.80	13.28	0.0030	0.0018
33	AAAC (AL3)	-	100	Oak	1	75	2.54	3.62	3.05	3.90	5.26	3.75	4.96	3.24	11.33	0.0036	0.0022	3.64	12.73	0.0032	0.0019	3.80	13.28	0.0030	0.0018
33	AAAC (AL3)	-	175	Elm	1	50	1.44	3.62	1.60	2.80	4.16	2.65	3.86	3.04	10.64	0.0038	0.0023	3.44	12.04	0.0033	0.0020	3.60	12.60	0.0032	0.0019
33	AAAC (AL3)	-	175	Elm	1	65	1.44	3.62	1.67	2.80	4.16	2.65	3.86	3.04	10.64	0.0038	0.0023	3.44	12.04	0.0033	0.0020	3.60	12.60	0.0032	0.0019
33	AAAC (AL3)	-	175	Elm	1	75	1.44	3.62	1.72	2.80	4.16	2.65	3.86	3.04	10.64	0.0038	0.0023	3.44	12.04	0.0033	0.0020	3.60	12.60	0.0032	0.0019
33	AAAC (AL3)	-	200	Poplar	1	50	1.27	3.62	1.41	2.63	3.99	2.48	3.69	3.00	10.49	0.0039	0.0023	3.40	11.89	0.0034	0.0020	3.56	12.45	0.0032	0.0019
33	AAAC (AL3)	-	200	Poplar	1	65	1.27	3.62	1.48	2.63	3.99	2.48	3.69	3.00	10.49	0.0039	0.0023	3.40	11.89	0.0034	0.0020	3.56	12.45	0.0032	0.0019
33	AAAC (AL3)	-	200	Poplar	1	75	1.27	3.62	1.53	2.63	3.99	2.48	3.69	3.00	10.49	0.0039	0.0023	3.40	11.89	0.0034	0.0020	3.56	12.45	0.0032	0.0019
33	AAAC (AL5)	-	100	Oak	1	50	2.44	3.62	2.71	3.80	5.16	3.65	4.86	3.24	11.33	0.0036	0.0022	3.64	12.73	0.0032	0.0019	3.80	13.28	0.0030	0.0018
33	AAAC (AL5)	-	100	Oak	1	65	2.44	3.62	2.84	3.80	5.16	3.65	4.86	3.24	11.33	0.0036	0.0022	3.64	12.73	0.0032	0.0019	3.80	13.28	0.0030	0.0018
33	AAAC (AL5)	-	100	Oak	1	75	2.44	3.62	2.93	3.80	5.16	3.65	4.86	3.24	11.33	0.0036	0.0022	3.64	12.73	0.0032	0.0019	3.80	13.28	0.0030	0.0018
33	AAAC (AL5)	-	175	Elm	1	50	1.38	3.62	1.53	2.74	4.10	2.59	3.79	3.04	10.64	0.0038	0.0023	3.44	12.04	0.0033	0.0020	3.60	12.60	0.0032	0.0019
33	AAAC (AL5)	-	175	Elm	1	65	1.38	3.62	1.60	2.74	4.10	2.59	3.79	3.04	10.64	0.0038	0.0023	3.44	12.04	0.0033	0.0020	3.60	12.60	0.0032	0.0019
33	AAAC (AL5)	-	175	Elm	1	75	1.38	3.62	1.65	2.74	4.10	2.59	3.79	3.04	10.64	0.0038	0.0023	3.44	12.04	0.0033	0.0020	3.60	12.60	0.0032	0.0019
33	AAAC (AL5)	-	200	Poplar	1	50	1.22	3.62	1.35	2.58	3.94	2.43	3.64	3.00	10.49	0.0039	0.0023	3.40	11.89	0.0034	0.0020	3.56	12.45	0.0032	0.0019
33	AAAC (AL5)	-	200	Poplar	1	65	1.22	3.62	1.42	2.58	3.94	2.43	3.64	3.00	10.49	0.0039	0.0023	3.40	11.89	0.0034	0.0020	3.56	12.45	0.0032	0.0019
33	AAAC (AL5)	-	200	Poplar	1	75	1.22	3.62	1.46	2.58	3.94	2.43	3.64	3.00	10.49	0.0039	0.0023	3.40	11.89	0.0034	0.0020	3.56	12.45	0.0032	0.0019

Table 38: 33kV All Aluminium Alloy Conductors (AAAC) Overhead Line Electrical Parameters (100MVA Base) – Flat Circuit Arrangement

	Conductors						Positive, Negative & Zero Sequence Resistance (100MVA base)							Positive, Negative & Zero Sequence Reactance and Capacitance (100MVA base) - DC Rutter Pole				Positive, Negative & Zero Sequence Reactance and Capacitance (100MVA base) - Double Circuit Mast Line (Normal)						Positive, Negative & Zero Sequence Reactance and Capacitance (100MVA base) - Double Circuit Mast Line (Transposed)						Positive, Negative & Zero Sequence Reactance and Capacitance (100MVA base) - Single Circuit Mast Line					
Voltage (kV)	Material Type	in^2	mm^2	Code	Bundled Conductors.	Design Temp (°C)	DC Resistance Ω/km (20°C)	Earth Wire Resistance	AC Resistance at Design Temp Ω/km	Resistance Ω/km - No EW (Portal Lines)	Resistance Ω/km - No EW (Double Circuit)	Resistance Ω/km - EW (Woodhouse Mast/ CE/C/37)	Resistance Ω/km - EW (Double Circuit)	Reactance Ω/km	Reactance Ω/km (No EW)	Susceptance µS/km	Susceptance µS/km	Reactance Ω/km	Reactance Ω/km (No EW)	Reactance Ω/km (EW)	Susceptance µS/km	Susceptance µS/km (NO EW)	Susceptance µS/km (EW)	Reactance Ω/km	Reactance Ω/km (No EW)	Reactance Ω/km (EW)	Susceptance µS/km	Susceptance µS/km (NO EW)	Susceptance µS/km (EW)	Reactance Ω/km	Reactance Ω/km (No EW)	Reactance Ω/km (EW)	Susceptance µS/km	Susceptance µS/km (NO EW)	Susceptance µS/km (EW)
U							R_{dc}	RE_{dc}	$R_1=R_2$	R_0	R_0	R_0	R_0	$X_1=X_2$	X_o	$B_1=B_2$	B_0	$X_1=X_2$	X_o	X_o	$B_1=B_2$	B_0	B_0	$X_1=X_2$	X_o	X_o	$B_1=B_2$	B_0	B_0	$X_1=X_2$	X_o	X_o	$B_1=B_2$	B_0	B_0
33	AAAC (AL3)	-	100	Oak	1	50	2.54	3.62	2.82	3.90	5.26	3.75	4.96	3.39	18.66	0.0036	0.0021	3.79	20.83	18.94	0.0034	0.0021	0.0024	3.50	19.26	17.51	0.0035	0.0021	0.0024	3.71	12.97	12.97	0.0031	0.0019	0.0022
33	AAAC (AL3)	-	100	Oak	1	65	2.54	3.62	2.96	3.90	5.26	3.75	4.96	3.39	18.66	0.0036	0.0021	3.79	20.83	18.94	0.0034	0.0021	0.0024	3.50	19.26	17.51	0.0035	0.0021	0.0024	3.71	12.97	12.97	0.0031	0.0019	0.0022
33	AAAC (AL3)	-	100	Oak	1	75	2.54	3.62	3.05	3.90	5.26	3.75	4.96	3.39	18.66	0.0036	0.0021	3.79	20.83	18.94	0.0034	0.0021	0.0024	3.50	19.26	17.51	0.0035	0.0021	0.0024	3.71	12.97	12.97	0.0031	0.0019	0.0022
33	AAAC (AL3)	-	175	Elm	1	50	1.44	3.62	1.60	2.80	4.16	2.65	3.86	3.20	17.59	0.0038	0.0023	3.59	19.76	17.96	0.0036	0.0022	0.0025	3.31	18.18	16.53	0.0037	0.0022	0.0026	3.51	12.29	12.29	0.0033	0.0020	0.0023
33	AAAC (AL3)	-	175	Elm	1	65	1.44	3.62	1.67	2.80	4.16	2.65	3.86	3.20	17.59	0.0038	0.0023	3.59	19.76	17.96	0.0036	0.0022	0.0025	3.31	18.18	16.53	0.0037	0.0022	0.0026	3.51	12.29	12.29	0.0033	0.0020	0.0023
33	AAAC (AL3)	-	175	Elm	1	75	1.44	3.62	1.72	2.80	4.16	2.65	3.86	3.20	17.59	0.0038	0.0023	3.59	19.76	17.96	0.0036	0.0022	0.0025	3.31	18.18	16.53	0.0037	0.0022	0.0026	3.51	12.29	12.29	0.0033	0.0020	0.0023
33	AAAC (AL3)	-	200	Poplar	1	50	1.27	3.62	1.41	2.63	3.99	2.48	3.69	3.16	17.35	0.0038	0.0023	3.55	19.52	17.74	0.0037	0.0022	0.0026	3.26	17.95	16.32	0.0037	0.0022	0.0026	3.47	12.14	12.14	0.0033	0.0020	0.0023
33	AAAC (AL3)	-	200	Poplar	1	65	1.27	3.62	1.48	2.63	3.99	2.48	3.69	3.16	17.35	0.0038	0.0023	3.55	19.52	17.74	0.0037	0.0022	0.0026	3.26	17.95	16.32	0.0037	0.0022	0.0026	3.47	12.14	12.14	0.0033	0.0020	0.0023
33	AAAC (AL3)	-	200	Poplar	1	75	1.27	3.62	1.53	2.63	3.99	2.48	3.69	3.16	17.35	0.0038	0.0023	3.55	19.52	17.74	0.0037	0.0022	0.0026	3.26	17.95	16.32	0.0037	0.0022	0.0026	3.47	12.14	12.14	0.0033	0.0020	0.0023
33	AAAC (AL5)	-	100	Oak	1	50	2.44	3.62	2.71	3.80	5.16	3.65	4.86	3.39	18.66	0.0036	0.0021	3.79	20.83	18.94	0.0034	0.0021	0.0024	3.50	19.26	17.51	0.0035	0.0021	0.0024	3.71	12.97	12.97	0.0031	0.0019	0.0022
33	AAAC (AL5)	-	100	Oak	1	65	2.44	3.62	2.84	3.80	5.16	3.65	4.86	3.39	18.66	0.0036	0.0021	3.79	20.83	18.94	0.0034	0.0021	0.0024	3.50	19.26	17.51	0.0035	0.0021	0.0024	3.71	12.97	12.97	0.0031	0.0019	0.0022
33	AAAC (AL5)	-	100	Oak	1	75	2.44	3.62	2.93	3.80	5.16	3.65	4.86	3.39	18.66	0.0036	0.0021	3.79	20.83	18.94	0.0034	0.0021	0.0024	3.50	19.26	17.51	0.0035	0.0021	0.0024	3.71	12.97	12.97	0.0031	0.0019	0.0022
33	AAAC (AL5)	-	175	Elm	1	50	1.38	3.62	1.53	2.74	4.10	2.59	3.79	3.20	17.59	0.0038	0.0023	3.59	19.76	17.96	0.0036	0.0022	0.0025	3.31	18.18	16.53	0.0037	0.0022	0.0026	3.51	12.29	12.29	0.0033	0.0020	0.0023
33	AAAC (AL5)	-	175	Elm	1	65	1.38	3.62	1.60	2.74	4.10	2.59	3.79	3.20	17.59	0.0038	0.0023	3.59	19.76	17.96	0.0036	0.0022	0.0025	3.31	18.18	16.53	0.0037	0.0022	0.0026	3.51	12.29	12.29	0.0033	0.0020	0.0023
33	AAAC (AL5)	-	175	Elm	1	75	1.38	3.62	1.65	2.74	4.10	2.59	3.79	3.20	17.59	0.0038	0.0023	3.59	19.76	17.96	0.0036	0.0022	0.0025	3.31	18.18	16.53	0.0037	0.0022	0.0026	3.51	12.29	12.29	0.0033	0.0020	0.0023
33	AAAC (AL5)	-	200	Poplar	1	50	1.22	3.62	1.35	2.58	3.94	2.43	3.64	3.16	17.35	0.0038	0.0023	3.55	19.52	17.74	0.0037	0.0022	0.0026	3.26	17.95	16.32	0.0037	0.0022	0.0026	3.47	12.14	12.14	0.0033	0.0020	0.0023
33	AAAC (AL5)	-	200	Poplar	1	65	1.22	3.62	1.42	2.58	3.94	2.43	3.64	3.16	17.35	0.0038	0.0023	3.55	19.52	17.74	0.0037	0.0022	0.0026	3.26	17.95	16.32	0.0037	0.0022	0.0026	3.47	12.14	12.14	0.0033	0.0020	0.0023
33	AAAC (AL5)	-	200	Poplar	1	75	1.22	3.62	1.46	2.58	3.94	2.43	3.64	3.16	17.35	0.0038	0.0023	3.55	19.52	17.74	0.0037	0.0022	0.0026	3.26	17.95	16.32	0.0037	0.0022	0.0026	3.47	12.14	12.14	0.0033	0.0020	0.0023

Table 39: 33kV All Aluminium Alloy Conductors (AAAC) Overhead Line Electrical Parameters (100MVA Base) – Single and Double Circuit Mast Lines

Appendix 3.5 – 66kV Overhead Line resistance, reactance and capacitance (100MVA Base)

	Conductors						Positive, Negative & Zero Sequence Resistance (100MVA base)							Positive, Negative & Zero Sequence Reactance and Capacitance (100MVA base) - 1.45m-2.4m spacing				Positive, Negative & Zero Sequence Reactance and Capacitance (100MVA base) - 2.74m-3.66m spacing			
Voltage (kV)	Material Type	in^2	mm^2	Code	Bundled Conductors	Design Temp (°C)	DC Resistance Ω/km (20°C)	Earth Wire Resistance	AC Resistance at Design Temp Ω/km	Resistance Ω/km - No EW (Portal Lines)	Resistance Ω/km - No EW (Double Circuit)	Resistance Ω/km - EW (Woodhouse Mast/ CE/C/37)	Resistance Ω/km - EW (Double Circuit)	Reactance Ω/km	Reactance Ω/km (No EW)	Susceptance µS/km	Susceptance µS/km	Reactance Ω/km	Reactance Ω/km (No EW)	Susceptance µS/km	Susceptance µS/km
U							R_{dc}	RE_{dc}	$R_1=R_2$	R_0	R_0	R_0	R_0	$X_1=X_2$	X_o	$B_1=B_2$	B_0	$X_1=X_2$	X_o	$B_1=B_2$	B_0
66	Copper	0.1	70	-	1	50	0.595	0.595	0.663	0.934	1.274	0.880	1.166	0.935	3.27	0.0124	0.0074	1.002	3.509	0.0115	0.0069
66	Copper	0.1	70	-	1	75	0.595	0.595	0.719	0.934	1.274	0.880	1.166	0.935	3.27	0.0124	0.0074	1.002	3.509	0.0115	0.0069
66	Copper	0.15	100	-	1	50	0.406	0.595	0.453	0.746	1.086	0.692	0.977	0.904	3.16	0.0127	0.0076	0.971	3.400	0.0118	0.0071
66	Copper	0.15	100	-	1	75	0.406	0.595	0.491	0.746	1.086	0.692	0.977	0.904	3.16	0.0127	0.0076	0.971	3.400	0.0118	0.0071
66	Copper	0.2	125	-	1	50	0.326	0.595	0.363	0.666	1.006	0.611	0.897	0.882	3.09	0.0130	0.0078	0.949	3.323	0.0121	0.0072
66	Copper	0.2	125	-	1	75	0.326	0.595	0.394	0.666	1.006	0.611	0.897	0.882	3.09	0.0130	0.0078	0.949	3.323	0.0121	0.0072

Table 40: 66kV Copper Overhead Line Electrical Parameters (100MVA Base) – Flat Circuit Arrangement

	Conductors						Positive, Negative & Zero Sequence Resistance (100MVA base)							Positive, Negative & Zero Sequence Reactance and Capacitance (100MVA base) - DC Rutter Pole				Positive, Negative & Zero Sequence Reactance and Capacitance (100MVA base) - Double Circuit Mast Line (Normal)						Positive, Negative & Zero Sequence Reactance and Capacitance (100MVA base) - Double Circuit Mast Line (Transposed)						Positive, Negative & Zero Sequence Reactance and Capacitance (100MVA base) - Single Circuit Mast Line					
Voltage (kV)	Material Type	in^2	mm^2	Code	Bundled Conductors	Design Temp (°C)	DC Resistance Ω/km (20°C)	Earth Wire Resistance	AC Resistance at Design Temp Ω/km	Resistance Ω/km - No EW (Portal Lines)	Resistance Ω/km - No EW (Double Circuit)	Resistance Ω/km - EW (Woodhouse Mast/ CE/C/37)	Resistance Ω/km - EW (Double Circuit)	Reactance Ω/km	Reactance Ω/km (No EW)	Susceptance µS/km	Susceptance µS/km	Reactance Ω/km	Reactance Ω/km (No EW)	Reactance Ω/km (EW)	Susceptance µS/km	Susceptance µS/km (NO EW)	Susceptance µS/km (EW)	Reactance Ω/km	Reactance Ω/km (No EW)	Reactance Ω/km (EW)	Susceptance µS/km	Susceptance µS/km (NO EW)	Susceptance µS/km (EW)	Reactance Ω/km	Reactance Ω/km (No EW)	Reactance Ω/km (EW)	Susceptance µS/km	Susceptance µS/km (NO EW)	Susceptance µS/km (EW)
U							R_{dc}	RE_{dc}	$R_1=R_2$	R_0	R_0	R_0	R_0	$X_1=X_2$	X_o	$B_1=B_2$	B_0	$X_1=X_2$	X_o	X_o	$B_1=B_2$	B_0	B_0	$X_1=X_2$	X_o	X_o	$B_1=B_2$	B_0	B_0	$X_1=X_2$	X_o	X_o	$B_1=B_2$	B_0	B_0
66	Copper	0.1	70	-	1	50	0.595	0.595	0.663	0.934	1.274	0.880	1.166	0.888	4.88	0.0136	0.0081	0.986	5.42	2.96	0.0130	0.0078	0.0091	0.915	5.03	2.74	0.0132	0.0079	0.0093	0.966	3.38	2.90	0.0119	0.0072	0.0084
66	Copper	0.1	70	-	1	75	0.595	0.595	0.719	0.934	1.274	0.880	1.166	0.888	4.88	0.0136	0.0081	0.986	5.42	2.96	0.0130	0.0078	0.0091	0.915	5.03	2.74	0.0132	0.0079	0.0093	0.966	3.38	2.90	0.0119	0.0072	0.0084
66	Copper	0.15	100	-	1	50	0.406	0.595	0.453	0.746	1.086	0.692	0.977	0.857	4.71	0.0140	0.0084	0.955	5.25	2.87	0.0134	0.0081	0.0094	0.884	4.86	2.65	0.0136	0.0082	0.0095	0.935	3.27	2.81	0.0123	0.0074	0.0086
66	Copper	0.15	100	-	1	75	0.406	0.595	0.491	0.746	1.086	0.692	0.977	0.857	4.71	0.0140	0.0084	0.955	5.25	2.87	0.0134	0.0081	0.0094	0.884	4.86	2.65	0.0136	0.0082	0.0095	0.935	3.27	2.81	0.0123	0.0074	0.0086
66	Copper	0.2	125	-	1	50	0.326	0.595	0.363	0.666	1.006	0.611	0.897	0.835	4.59	0.0144	0.0086	0.933	5.13	2.80	0.0138	0.0083	0.0097	0.862	4.74	2.59	0.0140	0.0084	0.0098	0.913	3.20	2.74	0.0126	0.0075	0.0088
66	Copper	0.2	125	-	1	75	0.326	0.595	0.394	0.666	1.006	0.611	0.897	0.835	4.59	0.0144	0.0086	0.933	5.13	2.80	0.0138	0.0083	0.0097	0.862	4.74	2.59	0.0140	0.0084	0.0098	0.913	3.20	2.74	0.0126	0.0075	0.0088

Table 41: 66kV Copper Overhead Line Electrical Parameters (100MVA Base) – Single and Double Circuit Mast Lines

	Conductors						Positive, Negative & Zero Sequence Resistance (100MVA base)							Positive, Negative & Zero Sequence Reactance and Capacitance (100MVA base) - 1.45m-2.4m spacing				Positive, Negative & Zero Sequence Reactance and Capacitance (100MVA base) - 2.74m-3.66m spacing			
Voltage (kV)	Material Type	in^2	mm^2	Code	Bundled Conductors	Design Temp (°C)	DC Resistance Ω/km (20°C)	Earth Wire Resistance	AC Resistance at Design Temp Ω/km	Resistance Ω/km - No EW (Portal Lines)	Resistance Ω/km - No EW (Double Circuit)	Resistance Ω/km - EW (Woodhouse Mast/ CE/C/37)	Resistance Ω/km - EW (Double Circuit)	Reactance Ω/km	Reactance Ω/km (No EW)	Susceptance µS/km	Susceptance µS/km	Reactance Ω/km	Reactance Ω/km (No EW)	Susceptance µS/km	Susceptance µS/km
U							R_{dc}	RE_{dc}	$R_1=R_2$	R_0	R_0	R_0	R_0	$X_1=X_2$	X_o	$B_1=B_2$	B_0	$X_1=X_2$	X_o	$B_1=B_2$	B_0
66	ASCR	0.1*	100	Dog	1	50	0.627	0.904	0.723	0.967	1.306	0.929	1.231	0.869	3.04	0.0130	0.0078	0.937	3.280	0.0120	0.0072
66	ASCR	0.1*	100	Dog	1	75	0.627	0.904	0.803	0.967	1.306	0.929	1.231	0.869	3.04	0.0130	0.0078	0.937	3.280	0.0120	0.0072
66	ASCR	0.15*	150	Dingo	1	50	0.418	0.904	0.482	0.758	1.098	0.720	1.022	0.860	3.01	0.0133	0.0080	0.927	3.246	0.0123	0.0074
66	ASCR	0.15*	150	Dingo	1	75	0.418	0.904	0.535	0.758	1.098	0.720	1.022	0.860	3.01	0.0133	0.0080	0.927	3.246	0.0123	0.0074
66	ASCR	0.15*	150	Wolf	1	50	0.420	0.904	0.484	0.760	1.100	0.722	1.024	0.839	2.94	0.0135	0.0081	0.907	3.175	0.0125	0.0075
66	ASCR	0.15*	150	Wolf	1	75	0.420	0.904	0.538	0.760	1.100	0.722	1.024	0.839	2.94	0.0135	0.0081	0.907	3.175	0.0125	0.0075
66	ASCR	0.175*	175	Lynx	1	50	0.363	0.904	0.418	0.703	1.042	0.665	0.967	0.828	2.90	0.0137	0.0082	0.896	3.137	0.0126	0.0076
66	ASCR	0.175*	175	Lynx	1	65	0.363	0.904	0.446	0.703	1.042	0.665	0.967	0.828	2.90	0.0137	0.0082	0.896	3.137	0.0126	0.0076
66	ASCR	0.175*	175	Lynx	1	75	0.363	0.904	0.464	0.703	1.042	0.665	0.967	0.828	2.90	0.0137	0.0082	0.896	3.137	0.0126	0.0076
66	ASCR	0.175*	175	Caracal	1	50	0.358	0.904	0.413	0.698	1.038	0.660	0.962	0.838	2.93	0.0137	0.0082	0.905	3.169	0.0126	0.0076
66	ASCR	0.175*	175	Caracal	1	65	0.358	0.904	0.440	0.698	1.038	0.660	0.962	0.838	2.93	0.0137	0.0082	0.905	3.169	0.0126	0.0076

Table 42: 66kV Aluminium Conductor Steel Reinforced (ACSR) Overhead Line Electrical Parameters (100MVA Base) – Flat Circuit Arrangement

*Copper Equivalent

	Conductors						Positive, Negative & Zero Sequence Resistance (100MVA base)							Positive, Negative & Zero Sequence Reactance and Capacitance (100MVA base) - DC Rutter Pole				Positive, Negative & Zero Sequence Reactance and Capacitance (100MVA base) - Double Circuit Mast Line (Normal)						Positive, Negative & Zero Sequence Reactance and Capacitance (100MVA base) - Double Circuit Mast Line (Transposed)						Positive, Negative & Zero Sequence Reactance and Capacitance (100MVA base) - Single Circuit Mast Line					
Voltage (kV)	Material Type	in^2	mm^2	Code	Bundled Conductors	Design Temp (°C)	DC Resistance Ω/km (20°C)	Earth Wire Resistance	AC Resistance at Design Temp Ω/km	Resistance Ω/km - No EW (Portal Lines)	Resistance Ω/km - No EW (Double Circuit)	Resistance Ω/km - EW (Woodhouse Mast/ CE/C/37)	Resistance Ω/km - EW (Double Circuit)	Reactance Ω/km	Reactance Ω/km (No EW)	Susceptance µS/km	Susceptance µS/km	Reactance Ω/km	Reactance Ω/km (No EW)	Reactance Ω/km (EW)	Susceptance µS/km	Susceptance µS/km (NO EW)	Susceptance µS/km (EW)	Reactance Ω/km	Reactance Ω/km (No EW)	Reactance Ω/km (EW)	Susceptance µS/km	Susceptance µS/km (NO EW)	Susceptance µS/km (EW)	Reactance Ω/km	Reactance Ω/km (No EW)	Reactance Ω/km (EW)	Susceptance µS/km	Susceptance µS/km (NO EW)	Susceptance µS/km (EW)
U							R_{dc}	RE_{dc}	$R_1=R_2$	R_0	R_0	R_0	R_0	$X_1=X_2$	X_o	$B_1=B_2$	B_0	$X_1=X_2$	X_o	X_o	$B_1=B_2$	B_0	B_0	$X_1=X_2$	X_o	X_o	$B_1=B_2$	B_0	B_0	$X_1=X_2$	X_o	X_o	$B_1=B_2$	B_0	B_0
66	ASCR	0.1*	100	Dog	1	50	0.627	0.904	0.723	0.967	1.306	0.929	1.231	0.822	4.52	0.0143	0.0086	0.921	5.06	4.60	0.0137	0.0082	0.0096	0.849	4.67	4.25	0.0139	0.0084	0.0097	0.901	3.15	3.15	0.0125	0.0075	0.0087
66	ASCR	0.1*	100	Dog	1	75	0.627	0.904	0.803	0.967	1.306	0.929	1.231	0.822	4.52	0.0143	0.0086	0.921	5.06	4.60	0.0137	0.0082	0.0096	0.849	4.67	4.25	0.0139	0.0084	0.0097	0.901	3.15	3.15	0.0125	0.0075	0.0087
66	ASCR	0.15*	150	Dingo	1	50	0.418	0.904	0.482	0.758	1.098	0.720	1.022	0.813	4.47	0.0148	0.0089	0.911	5.01	4.56	0.0141	0.0085	0.0099	0.840	4.62	4.20	0.0144	0.0086	0.0101	0.891	3.12	3.12	0.0128	0.0077	0.0090
66	ASCR	0.15*	150	Dingo	1	75	0.418	0.904	0.535	0.758	1.098	0.720	1.022	0.813	4.47	0.0148	0.0089	0.911	5.01	4.56	0.0141	0.0085	0.0099	0.840	4.62	4.20	0.0144	0.0086	0.0101	0.891	3.12	3.12	0.0128	0.0077	0.0090
66	ASCR	0.15*	150	Wolf	1	50	0.420	0.904	0.484	0.760	1.100	0.722	1.024	0.792	4.36	0.0150	0.0090	0.891	4.90	4.45	0.0144	0.0086	0.0100	0.819	4.51	4.10	0.0146	0.0087	0.0102	0.871	3.05	3.05	0.0130	0.0078	0.0091
66	ASCR	0.15*	150	Wolf	1	75	0.420	0.904	0.538	0.760	1.100	0.722	1.024	0.792	4.36	0.0150	0.0090	0.891	4.90	4.45	0.0144	0.0086	0.0100	0.819	4.51	4.10	0.0146	0.0087	0.0102	0.871	3.05	3.05	0.0130	0.0078	0.0091
66	ASCR	0.175*	175	Lynx	1	50	0.363	0.904	0.418	0.703	1.042	0.665	0.967	0.782	4.30	0.0152	0.0091	0.880	4.84	4.40	0.0146	0.0087	0.0102	0.808	4.45	4.04	0.0148	0.0089	0.0104	0.860	3.01	3.01	0.0132	0.0079	0.0092
66	ASCR	0.175*	175	Lynx	1	65	0.363	0.904	0.446	0.703	1.042	0.665	0.967	0.782	4.30	0.0152	0.0091	0.880	4.84	4.40	0.0146	0.0087	0.0102	0.808	4.45	4.04	0.0148	0.0089	0.0104	0.860	3.01	3.01	0.0132	0.0079	0.0092
66	ASCR	0.175*	175	Lynx	1	75	0.363	0.904	0.464	0.703	1.042	0.665	0.967	0.782	4.30	0.0152	0.0091	0.880	4.84	4.40	0.0146	0.0087	0.0102	0.808	4.45	4.04	0.0148	0.0089	0.0104	0.860	3.01	3.01	0.0132	0.0079	0.0092
66	ASCR	0.175*	175	Caracal	1	50	0.358	0.904	0.413	0.698	1.038	0.660	0.962	0.791	4.35	0.0152	0.0091	0.889	4.89	4.45	0.0146	0.0087	0.0102	0.818	4.50	4.09	0.0148	0.0089	0.0104	0.869	3.04	3.04	0.0132	0.0079	0.0092
66	ASCR	0.175*	175	Caracal	1	65	0.358	0.904	0.440	0.698	1.038	0.660	0.962	0.791	4.35	0.0152	0.0091	0.889	4.89	4.45	0.0146	0.0087	0.0102	0.818	4.50	4.09	0.0148	0.0089	0.0104	0.869	3.04	3.04	0.0132	0.0079	0.0092

Table 43: 66kV Aluminium Conductor Steel Reinforced (ACSR) Overhead Line Electrical Parameters (100MVA Base) – Single and Double Circuit Mast Lines

*Copper Equivalent

	Conductors						Positive, Negative & Zero Sequence Resistance (100MVA base)							Positive, Negative & Zero Sequence Reactance and Capacitance (100MVA base) - 1.45m-2.4m spacing				Positive, Negative & Zero Sequence Reactance and Capacitance (100MVA base) - 2.74m-3.66m spacing			
Voltage (kV)	Material Type	in^2	mm^2	Code	Bundled Conductors	Design Temp (°C)	DC Resistance Ω/km (20°C)	Earth Wire Resistance	AC Resistance at Design Temp Ω/km	Resistance Ω/km - No EW (Portal Lines)	Resistance Ω/km - No EW (Double Circuit)	Resistance Ω/km - EW (Woodhouse Mast/ CE/C/37)	Resistance Ω/km - EW (Double Circuit)	Reactance Ω/km	Reactance Ω/km (No EW)	Susceptance µS/km	Susceptance µS/km	Reactance Ω/km	Reactance Ω/km (No EW)	Susceptance µS/km	Susceptance µS/km
U							R_{dc}	RE_{dc}	$R_1=R_2$	R_0	R_0	R_0	R_0	$X_1=X_2$	X_o	$B_1=B_2$	B_0	$X_1=X_2$	X_o	$B_1=B_2$	B_0
66	AAAC (AL3)	-	100	Oak	1	50	0.636	0.904	0.705	0.976	1.316	0.938	1.240	0.895	3.13	0.0129	0.0078	0.963	3.370	0.0120	0.0072
66	AAAC (AL3)	-	100	Oak	1	65	0.636	0.904	0.739	0.976	1.316	0.938	1.240	0.895	3.13	0.0129	0.0078	0.963	3.370	0.0120	0.0072
66	AAAC (AL3)	-	100	Oak	1	75	0.636	0.904	0.762	0.976	1.316	0.938	1.240	0.895	3.13	0.0129	0.0078	0.963	3.370	0.0120	0.0072
66	AAAC (AL3)	-	175	Elm	1	50	0.360	0.904	0.399	0.700	1.040	0.662	0.964	0.846	2.96	0.0136	0.0082	0.914	3.200	0.0126	0.0075
66	AAAC (AL3)	-	175	Elm	1	65	0.360	0.904	0.418	0.700	1.040	0.662	0.964	0.846	2.96	0.0136	0.0082	0.914	3.200	0.0126	0.0075
66	AAAC (AL3)	-	175	Elm	1	75	0.360	0.904	0.431	0.700	1.040	0.662	0.964	0.846	2.96	0.0136	0.0082	0.914	3.200	0.0126	0.0075
66	AAAC (AL3)	-	200	Poplar	1	50	0.318	0.904	0.353	0.658	0.998	0.620	0.922	0.836	2.92	0.0138	0.0083	0.903	3.162	0.0127	0.0076
66	AAAC (AL3)	-	200	Poplar	1	65	0.318	0.904	0.370	0.658	0.998	0.620	0.922	0.836	2.92	0.0138	0.0083	0.903	3.162	0.0127	0.0076
66	AAAC (AL3)	-	200	Poplar	1	75	0.318	0.904	0.381	0.658	0.998	0.620	0.922	0.836	2.92	0.0138	0.0083	0.903	3.162	0.0127	0.0076
66	AAAC (AL5)	-	100	Oak	1	50	0.611	0.904	0.677	0.951	1.290	0.913	1.215	0.895	3.13	0.0129	0.0078	0.963	3.370	0.0213	0.0128
66	AAAC (AL5)	-	100	Oak	1	65	0.611	0.904	0.710	0.951	1.290	0.913	1.215	0.895	3.13	0.0129	0.0078	0.963	3.370	0.0213	0.0128
66	AAAC (AL5)	-	100	Oak	1	75	0.611	0.904	0.732	0.951	1.290	0.913	1.215	0.895	3.13	0.0129	0.0078	0.963	3.370	0.0213	0.0128
66	AAAC (AL5)	-	175	Elm	1	50	0.344	0.904	0.382	0.684	1.024	0.646	0.948	0.846	2.96	0.0136	0.0082	0.914	3.200	0.0216	0.0130
66	AAAC (AL5)	-	175	Elm	1	65	0.344	0.904	0.400	0.684	1.024	0.646	0.948	0.846	2.96	0.0136	0.0082	0.914	3.200	0.0216	0.0130
66	AAAC (AL5)	-	175	Elm	1	75	0.344	0.904	0.413	0.684	1.024	0.646	0.948	0.846	2.96	0.0136	0.0082	0.914	3.200	0.0216	0.0130
66	AAAC (AL5)	-	200	Poplar	1	50	0.305	0.904	0.338	0.645	0.985	0.607	0.909	0.836	2.92	0.0138	0.0083	0.903	3.162	0.0217	0.0130
66	AAAC (AL5)	-	200	Poplar	1	65	0.305	0.904	0.355	0.645	0.985	0.607	0.909	0.836	2.92	0.0138	0.0083	0.903	3.162	0.0217	0.0130
66	AAAC (AL5)	-	200	Poplar	1	75	0.305	0.904	0.366	0.645	0.985	0.607	0.909	0.836	2.92	0.0138	0.0083	0.903	3.162	0.0217	0.0130

Table 44: 66kV All Aluminium Alloy Conductors (AAAC) Overhead Line Electrical Parameters (100MVA Base) – Flat Circuit Arrangement

	Conductors						Positive, Negative & Zero Sequence Resistance (100MVA base)							Positive, Negative & Zero Sequence Reactance and Capacitance (100MVA base) - DC Rutter Pole				Positive, Negative & Zero Sequence Reactance and Capacitance (100MVA base) - Double Circuit Mast Line (Normal)						Positive, Negative & Zero Sequence Reactance and Capacitance (100MVA base) - Double Circuit Mast Line (Transposed)						Positive, Negative & Zero Sequence Reactance and Capacitance (100MVA base) - Single Circuit Mast Line					
Voltage (kV)	Material Type	in^2	mm^2	Code	Bundled Conductors	Design Temp (°C)	DC Resistance Ω/km (20°C)	Earth Wire Resistance	AC Resistance at Design Temp Ω/km	Resistance Ω/km - No EW (Portal Lines)	Resistance Ω/km - No EW (Double Circuit)	Resistance Ω/km - EW (Woodhouse Mast/ CE/C/37)	Resistance Ω/km - EW (Double Circuit)	Reactance Ω/km	Reactance Ω/km (No EW)	Susceptance µS/km	Susceptance µS/km	Reactance Ω/km	Reactance Ω/km (No EW)	Reactance Ω/km (EW)	Susceptance µS/km	Susceptance µS/km (NO EW)	Susceptance µS/km (EW)	Reactance Ω/km	Reactance Ω/km (No EW)	Reactance Ω/km (EW)	Susceptance µS/km	Susceptance µS/km (NO EW)	Susceptance µS/km (EW)	Reactance Ω/km	Reactance Ω/km (No EW)	Reactance Ω/km (EW)	Susceptance µS/km	Susceptance µS/km (NO EW)	Susceptance µS/km (EW)
U							R_{dc}	RE_{dc}	$R_1=R_2$	R_0	R_0	R_0	R_0	$X_1=X_2$	X_o	$B_1=B_2$	B_0	$X_1=X_2$	X_o	X_o	$B_1=B_2$	B_0	B_0	$X_1=X_2$	X_o	X_o	$B_1=B_2$	B_0	B_0	$X_1=X_2$	X_o	X_o	$B_1=B_2$	B_0	B_0
66	AAAC (AL3)	-	100	Oak	1	50	0.636	0.904	0.705	0.976	1.316	0.938	1.240	0.848	4.67	0.0143	0.0086	0.947	5.21	4.73	0.0137	0.0082	0.0096	0.875	4.81	4.38	0.0139	0.0083	0.0097	0.927	3.24	3.24	0.0125	0.0075	0.0087
66	AAAC (AL3)	-	100	Oak	1	65	0.636	0.904	0.739	0.976	1.316	0.938	1.240	0.848	4.67	0.0143	0.0086	0.947	5.21	4.73	0.0137	0.0082	0.0096	0.875	4.81	4.38	0.0139	0.0083	0.0097	0.927	3.24	3.24	0.0125	0.0075	0.0087
66	AAAC (AL3)	-	100	Oak	1	75	0.636	0.904	0.762	0.976	1.316	0.938	1.240	0.848	4.67	0.0143	0.0086	0.947	5.21	4.73	0.0137	0.0082	0.0096	0.875	4.81	4.38	0.0139	0.0083	0.0097	0.927	3.24	3.24	0.0125	0.0075	0.0087
66	AAAC (AL3)	-	175	Elm	1	50	0.360	0.904	0.399	0.700	1.040	0.662	0.964	0.800	4.40	0.0151	0.0091	0.898	4.94	4.49	0.0144	0.0087	0.0101	0.827	4.55	4.13	0.0147	0.0088	0.0103	0.878	3.07	3.07	0.0131	0.0079	0.0092
66	AAAC (AL3)	-	175	Elm	1	65	0.360	0.904	0.418	0.700	1.040	0.662	0.964	0.800	4.40	0.0151	0.0091	0.898	4.94	4.49	0.0144	0.0087	0.0101	0.827	4.55	4.13	0.0147	0.0088	0.0103	0.878	3.07	3.07	0.0131	0.0079	0.0092
66	AAAC (AL3)	-	175	Elm	1	75	0.360	0.904	0.431	0.700	1.040	0.662	0.964	0.800	4.40	0.0151	0.0091	0.898	4.94	4.49	0.0144	0.0087	0.0101	0.827	4.55	4.13	0.0147	0.0088	0.0103	0.878	3.07	3.07	0.0131	0.0079	0.0092
66	AAAC (AL3)	-	200	Poplar	1	50	0.318	0.904	0.353	0.658	0.998	0.620	0.922	0.789	4.34	0.0153	0.0092	0.887	4.88	4.44	0.0146	0.0088	0.0102	0.816	4.49	4.08	0.0149	0.0089	0.0104	0.867	3.04	3.04	0.0132	0.0079	0.0093
66	AAAC (AL3)	-	200	Poplar	1	65	0.318	0.904	0.370	0.658	0.998	0.620	0.922	0.789	4.34	0.0153	0.0092	0.887	4.88	4.44	0.0146	0.0088	0.0102	0.816	4.49	4.08	0.0149	0.0089	0.0104	0.867	3.04	3.04	0.0132	0.0079	0.0093
66	AAAC (AL3)	-	200	Poplar	1	75	0.318	0.904	0.381	0.658	0.998	0.620	0.922	0.789	4.34	0.0153	0.0092	0.887	4.88	4.44	0.0146	0.0088	0.0102	0.816	4.49	4.08	0.0149	0.0089	0.0104	0.867	3.04	3.04	0.0132	0.0079	0.0093
66	AAAC (AL5)	-	100	Oak	1	50	0.611	0.904	0.677	0.951	1.290	0.913	1.215	0.848	4.67	0.0143	0.0086	0.947	5.21	4.73	0.0137	0.0082	0.0096	0.875	4.81	4.38	0.0139	0.0083	0.0097	0.927	3.24	3.24	0.0125	0.0075	0.0087
66	AAAC (AL5)	-	100	Oak	1	65	0.611	0.904	0.710	0.951	1.290	0.913	1.215	0.848	4.67	0.0143	0.0086	0.947	5.21	4.73	0.0137	0.0082	0.0096	0.875	4.81	4.38	0.0139	0.0083	0.0097	0.927	3.24	3.24	0.0125	0.0075	0.0087
66	AAAC (AL5)	-	100	Oak	1	75	0.611	0.904	0.732	0.951	1.290	0.913	1.215	0.848	4.67	0.0143	0.0086	0.947	5.21	4.73	0.0137	0.0082	0.0096	0.875	4.81	4.38	0.0139	0.0083	0.0097	0.927	3.24	3.24	0.0125	0.0075	0.0087
66	AAAC (AL5)	-	175	Elm	1	50	0.344	0.904	0.382	0.684	1.024	0.646	0.948	0.800	4.40	0.0151	0.0091	0.898	4.94	4.49	0.0144	0.0087	0.0101	0.827	4.55	4.13	0.0147	0.0088	0.0103	0.878	3.07	3.07	0.0131	0.0079	0.0092
66	AAAC (AL5)	-	175	Elm	1	65	0.344	0.904	0.400	0.684	1.024	0.646	0.948	0.800	4.40	0.0151	0.0091	0.898	4.94	4.49	0.0144	0.0087	0.0101	0.827	4.55	4.13	0.0147	0.0088	0.0103	0.878	3.07	3.07	0.0131	0.0079	0.0092
66	AAAC (AL5)	-	175	Elm	1	75	0.344	0.904	0.413	0.684	1.024	0.646	0.948	0.800	4.40	0.0151	0.0091	0.898	4.94	4.49	0.0144	0.0087	0.0101	0.827	4.55	4.13	0.0147	0.0088	0.0103	0.878	3.07	3.07	0.0131	0.0079	0.0092
66	AAAC (AL5)	-	200	Poplar	1	50	0.305	0.904	0.338	0.645	0.985	0.607	0.909	0.789	4.34	0.0153	0.0092	0.887	4.88	4.44	0.0146	0.0088	0.0102	0.816	4.49	4.08	0.0149	0.0089	0.0104	0.867	3.04	3.04	0.0132	0.0079	0.0093
66	AAAC (AL5)	-	200	Poplar	1	65	0.305	0.904	0.355	0.645	0.985	0.607	0.909	0.789	4.34	0.0153	0.0092	0.887	4.88	4.44	0.0146	0.0088	0.0102	0.816	4.49	4.08	0.0149	0.0089	0.0104	0.867	3.04	3.04	0.0132	0.0079	0.0093
66	AAAC (AL5)	-	200	Poplar	1	75	0.305	0.904	0.366	0.645	0.985	0.607	0.909	0.789	4.34	0.0153	0.0092	0.887	4.88	4.44	0.0146	0.0088	0.0102	0.816	4.49	4.08	0.0149	0.0089	0.0104	0.867	3.04	3.04	0.0132	0.0079	0.0093

Table 45: 66kV All Aluminium Alloy Conductors (AAAC) Overhead Line Electrical Parameters (100MVA Base) – Single and Double Circuit Mast Lines

Appendix 3.6 – 132kV Overhead Line resistance, reactance and capacitance (100MVA Base)

	Conductors						Positive, Negative & Zero Sequence Resistance (100MVA base)					Positive, Negative & Zero Sequence Reactance and Capacitance (100MVA base) - Single Circuit Tower				Positive, Negative & Zero Sequence Reactance and Capacitance (100MVA base) - Double Circuit 1 (Normal)				Positive, Negative & Zero Sequence Reactance and Capacitance (100MVA base) - Double Circuit 1 (Transposed)				Positive, Negative & Zero Sequence Reactance and Capacitance (100MVA base) - Double Circuit 2 (Normal)				Positive, Negative & Zero Sequence Reactance and Capacitance (100MVA base) - Double Circuit 2 (Transposed)			
Voltage (kV)	Material Type	strands	mm^2/in^2	Code	No.	Design Temp (°C)	DC Resistance Ω/km (20°C)	Earth Wire Resistance	AC Resistance at Design Temp Ω/km	Resistance Ω/km - EW (Single Circuit)	Resistance Ω/km - EW (Double Circuit)	Reactance Ω/km	Reactance Ω/km (EW)	Susceptance µS	Susceptance µS/km (EW)	Reactance Ω/km	Reactance Ω/km (EW)	Susceptance µS	Susceptance µS/km (EW)	Reactance Ω/km	Reactance Ω/km (EW)	Susceptance µS	Susceptance µS/km (EW)	Reactance Ω/km	Reactance Ω/km (EW)	Susceptance µS	Susceptance µS/km (EW)	Reactance Ω/km	Reactance Ω/km (EW)	Susceptance µS	Susceptance µS/km (EW)
U							R_{dc}	RE_{dc}	$R_1=R_2$	R_0	R_0	$X_1=X_2$	X_0	$B_1=B_2$	B_0	$X_1=X_2$	X_0	$B_1=B_2$	B_0	$X_1=X_2$	X_0	$B_1=B_2$	B_0	$X_1=X_2$	X_0	$B_1=B_2$	B_0	$X_1=X_2$	X_0	$B_1=B_2$	B_0
132	ACSR	30	150	Wolf	1	50	0.105	0.226	0.121	0.181	0.256	0.233	0.817	0.0485	0.0339	0.240	1.199	0.0525	0.0367	0.223	1.114	0.0532	0.0372	0.259	1.294	0.0492	0.0344	0.239	1.195	0.0499	0.0350
132	ACSR	30	150	Wolf	1	65	0.105	0.226	0.129	0.181	0.256	0.233	0.817	0.0485	0.0339	0.240	1.199	0.0525	0.0367	0.223	1.114	0.0532	0.0372	0.259	1.294	0.0492	0.0344	0.239	1.195	0.0499	0.0350
132	ACSR	30	150	Wolf	1	75	0.105	0.226	0.134	0.181	0.256	0.233	0.817	0.0485	0.0339	0.240	1.199	0.0525	0.0367	0.223	1.114	0.0532	0.0372	0.259	1.294	0.0492	0.0344	0.239	1.195	0.0499	0.0350
132	ACSR	30	175	Lynx	1	50	0.090	0.226	0.104	0.166	0.241	0.233	0.817	0.0485	0.0339	0.240	1.199	0.0525	0.0367	0.223	1.114	0.0532	0.0372	0.259	1.294	0.0492	0.0344	0.239	1.195	0.0499	0.0350
132	ACSR	30	175	Lynx	1	65	0.090	0.226	0.111	0.166	0.241	0.233	0.817	0.0485	0.0339	0.240	1.199	0.0525	0.0367	0.223	1.114	0.0532	0.0372	0.259	1.294	0.0492	0.0344	0.239	1.195	0.0499	0.0350
132	ACSR	30	175	Lynx	1	75	0.090	0.226	0.116	0.166	0.241	0.233	0.817	0.0485	0.0339	0.240	1.199	0.0525	0.0367	0.223	1.114	0.0532	0.0372	0.259	1.294	0.0492	0.0344	0.239	1.195	0.0499	0.0350
132	ASCR	30	175	Lynx	2	50	0.045	0.226	0.052	0.098	0.174	0.168	0.589	0.0485	0.0339	0.231	1.154	0.0525	0.0367	0.219	1.097	0.0532	0.0372	0.254	1.271	0.0492	0.0344	0.241	1.204	0.0499	0.0350
132	ASCR	30	175	Lynx	2	65	0.045	0.226	0.056	0.098	0.174	0.168	0.589	0.0485	0.0339	0.231	1.154	0.0525	0.0367	0.219	1.097	0.0532	0.0372	0.254	1.271	0.0492	0.0344	0.241	1.204	0.0499	0.0350
132	ASCR	30	175	Lynx	2	75	0.045	0.226	0.058	0.098	0.174	0.168	0.589	0.0485	0.0339	0.231	1.154	0.0525	0.0367	0.219	1.097	0.0532	0.0372	0.254	1.271	0.0492	0.0344	0.241	1.204	0.0499	0.0350
132	ACSR	54	400	Zebra	1	50	0.039	0.226	0.045	0.114	0.190	0.220	0.771	0.0516	0.0361	0.227	1.134	0.0562	0.0393	0.210	1.049	0.0570	0.0399	0.246	1.229	0.0524	0.0367	0.226	1.130	0.0533	0.0373
132	ACSR	54	400	Zebra	1	65	0.039	0.226	0.048	0.114	0.190	0.220	0.771	0.0516	0.0361	0.227	1.134	0.0562	0.0393	0.210	1.049	0.0570	0.0399	0.246	1.229	0.0524	0.0367	0.226	1.130	0.0533	0.0373
132	ACSR	54	400	Zebra	1	75	0.039	0.226	0.050	0.114	0.190	0.220	0.771	0.0516	0.0361	0.227	1.134	0.0562	0.0393	0.210	1.049	0.0570	0.0399	0.246	1.229	0.0524	0.0367	0.226	1.130	0.0533	0.0373

Table 46: 132kV Aluminium Conductor Steel Reinforced (ACSR) Overhead Line Electrical Parameters (100MVA Base) – Single and Double Circuit Tower Lines

	Conductors						Positive, Negative & Zero Sequence Resistance (100MVA base)					Positive, Negative & Zero Sequence Reactance and Capacitance (100MVA base) - Single Circuit Tower				Positive, Negative & Zero Sequence Reactance and Capacitance (100MVA base) - Double Circuit 1 (Normal)				Positive, Negative & Zero Sequence Reactance and Capacitance (100MVA base) - Double Circuit 1 (Transposed)				Positive, Negative & Zero Sequence Reactance and Capacitance (100MVA base) - Double Circuit 2 (Normal)				Positive, Negative & Zero Sequence Reactance and Capacitance (100MVA base) - Double Circuit 2 (Transposed)			
Voltage (kV)	Material Type	strands	mm^2/in^2	Code	No.	Design Temp (°C)	DC Resistance Ω/km (20°C)	Earth Wire Resistance	AC Resistance at Design Temp Ω/km	Resistance Ω/km - EW (Single Circuit)	Resistance Ω/km - EW (Double Circuit)	Reactance Ω/km	Reactance Ω/km (EW)	Susceptance µS	Susceptance µS/km (EW)	Reactance Ω/km	Reactance Ω/km (EW)	Susceptance µS	Susceptance µS/km (EW)	Reactance Ω/km	Reactance Ω/km (EW)	Susceptance µS	Susceptance µS/km (EW)	Reactance Ω/km	Reactance Ω/km (EW)	Susceptance µS	Susceptance µS/km (EW)	Reactance Ω/km	Reactance Ω/km (EW)	Susceptance µS	Susceptance µS/km (EW)
U							R_{dc}	RE_{dc}	$R_1=R_2$	R_0	R_0	$X_1=X_2$	X_0	$B_1=B_2$	B_0	$X_1=X_2$	X_0	$B_1=B_2$	B_0	$X_1=X_2$	X_0	$B_1=B_2$	B_0	$X_1=X_2$	X_0	$B_1=B_2$	B_0	$X_1=X_2$	X_0	$B_1=B_2$	B_0
132	AAAC (AL3)	7	100	Oak	1	50	0.159	0.226	0.176	0.234	0.310	0.180	0.629	0.0653	0.0457	0.186	0.931	0.0728	0.0510	0.169	0.846	0.0742	0.0519	0.205	1.026	0.0666	0.0466	0.185	0.926	0.0680	0.0476
132	AAAC (AL3)	7	100	Oak	1	65	0.159	0.226	0.185	0.234	0.310	0.180	0.629	0.0653	0.0457	0.186	0.931	0.0728	0.0510	0.169	0.846	0.0742	0.0519	0.205	1.026	0.0666	0.0466	0.185	0.926	0.0680	0.0476
132	AAAC (AL3)	7	100	Oak	1	75	0.159	0.226	0.190	0.234	0.310	0.180	0.629	0.0653	0.0457	0.186	0.931	0.0728	0.0510	0.169	0.846	0.0742	0.0519	0.205	1.026	0.0666	0.0466	0.185	0.926	0.0680	0.0476
132	AAAC (AL3)	37	200	Poplar	1	50	0.080	0.226	0.088	0.155	0.231	0.235	0.823	0.0487	0.0341	0.242	1.209	0.0527	0.0369	0.225	1.123	0.0534	0.0374	0.261	1.304	0.0494	0.0346	0.241	1.204	0.0501	0.0351
132	AAAC (AL3)	37	200	Poplar	1	65	0.080	0.226	0.092	0.155	0.231	0.235	0.823	0.0487	0.0341	0.242	1.209	0.0527	0.0369	0.225	1.123	0.0534	0.0374	0.261	1.304	0.0494	0.0346	0.241	1.204	0.0501	0.0351
132	AAAC (AL3)	37	200	Poplar	1	75	0.080	0.226	0.096	0.155	0.231	0.235	0.823	0.0487	0.0341	0.242	1.209	0.0527	0.0369	0.225	1.123	0.0534	0.0374	0.261	1.304	0.0494	0.0346	0.241	1.204	0.0501	0.0351
132	AAAC (AL3)	31	300	Upas	1	50	0.053	0.226	0.058	0.128	0.204	0.225	0.787	0.0504	0.0353	0.231	1.157	0.0547	0.0383	0.214	1.072	0.0555	0.0388	0.250	1.252	0.0511	0.0358	0.231	1.153	0.0519	0.0364
132	AAAC (AL3)	31	300	Upas	1	65	0.053	0.226	0.061	0.128	0.204	0.225	0.787	0.0504	0.0353	0.231	1.157	0.0547	0.0383	0.214	1.072	0.0555	0.0388	0.250	1.252	0.0511	0.0358	0.231	1.153	0.0519	0.0364
132	AAAC (AL3)	31	300	Upas	1	75	0.053	0.226	0.063	0.128	0.204	0.225	0.787	0.0504	0.0353	0.231	1.157	0.0547	0.0383	0.214	1.072	0.0555	0.0388	0.250	1.252	0.0511	0.0358	0.231	1.153	0.0519	0.0364
132	AAAC (AL3)	61	500	Rubus	1	50	0.033	0.226	0.036	0.108	0.184	0.219	0.765	0.0525	0.0367	0.225	1.126	0.0572	0.0400	0.208	1.041	0.0580	0.0406	0.244	1.221	0.0533	0.0373	0.224	1.121	0.0542	0.0379
132	AAAC (AL3)	61	500	Rubus	1	65	0.033	0.226	0.038	0.108	0.184	0.219	0.765	0.0525	0.0367	0.225	1.126	0.0572	0.0400	0.208	1.041	0.0580	0.0406	0.244	1.221	0.0533	0.0373	0.224	1.121	0.0542	0.0379
132	AAAC (AL3)	61	500	Rubus	1	75	0.033	0.226	0.039	0.108	0.184	0.219	0.765	0.0525	0.0367	0.225	1.126	0.0572	0.0400	0.208	1.041	0.0580	0.0406	0.244	1.221	0.0533	0.0373	0.224	1.121	0.0542	0.0379
132	AAAC (AL3)	7	100	Oak	1	50	0.153	0.226	0.169	0.153	0.153	0.180	0.629	0.0653	0.0457	0.186	0.931	0.0728	0.0510	0.169	0.846	0.0742	0.0519	0.205	1.026	0.0666	0.0466	0.185	0.926	0.0680	0.0476
132	AAAC (AL3)	7	100	Oak	1	65	0.153	0.226	0.177	0.153	0.153	0.180	0.629	0.0653	0.0457	0.186	0.931	0.0728	0.0510	0.169	0.846	0.0742	0.0519	0.205	1.026	0.0666	0.0466	0.185	0.926	0.0680	0.0476
132	AAAC (AL3)	7	100	Oak	1	75	0.153	0.226	0.183	0.153	0.153	0.180	0.629	0.0653	0.0457	0.186	0.931	0.0728	0.0510	0.169	0.846	0.0742	0.0519	0.205	1.026	0.0666	0.0466	0.185	0.926	0.0680	0.0476
132	AAAC (AL5)	37	200	Poplar	1	50	0.076	0.226	0.085	0.076	0.076	0.235	0.823	0.0487	0.0341	0.242	1.209	0.0527	0.0369	0.225	1.123	0.0534	0.0374	0.261	1.304	0.0494	0.0346	0.241	1.204	0.0501	0.0351
132	AAAC (AL5)	37	200	Poplar	1	65	0.076	0.226	0.089	0.076	0.076	0.235	0.823	0.0487	0.0341	0.242	1.209	0.0527	0.0369	0.225	1.123	0.0534	0.0374	0.261	1.304	0.0494	0.0346	0.241	1.204	0.0501	0.0351
132	AAAC (AL5)	37	200	Poplar	1	75	0.076	0.226	0.091	0.076	0.076	0.235	0.823	0.0487	0.0341	0.242	1.209	0.0527	0.0369	0.225	1.123	0.0534	0.0374	0.261	1.304	0.0494	0.0346	0.241	1.204	0.0501	0.0351
132	AAAC (AL5)	31	300	Upas	1	50	0.051	0.226	0.056	0.051	0.051	0.225	0.787	0.0504	0.0353	0.231	1.157	0.0547	0.0383	0.214	1.072	0.0555	0.0388	0.250	1.252	0.0511	0.0358	0.231	1.153	0.0519	0.0364
132	AAAC (AL5)	31	300	Upas	1	65	0.051	0.226	0.059	0.051	0.051	0.225	0.787	0.0504	0.0353	0.231	1.157	0.0547	0.0383	0.214	1.072	0.0555	0.0388	0.250	1.252	0.0511	0.0358	0.231	1.153	0.0519	0.0364
132	AAAC (AL5)	31	300	Upas	1	75	0.051	0.226	0.061	0.051	0.051	0.225	0.787	0.0504	0.0353	0.231	1.157	0.0547	0.0383	0.214	1.072	0.0555	0.0388	0.250	1.252	0.0511	0.0358	0.231	1.153	0.0519	0.0364
132	AAAC (AL5)	61	500	Rubus	1	50	0.031	0.226	0.034	0.031	0.031	0.219	0.765	0.0525	0.0367	0.225	1.126	0.0572	0.0400	0.208	1.041	0.0580	0.0406	0.244	1.221	0.0533	0.0373	0.224	1.121	0.0542	0.0379
132	AAAC (AL5)	61	500	Rubus	1	65	0.031	0.226	0.036	0.031	0.031	0.219	0.765	0.0525	0.0367	0.225	1.126	0.0572	0.0400	0.208	1.041	0.0580	0.0406	0.244	1.221	0.0533	0.0373	0.224	1.121	0.0542	0.0379
132	AAAC (AL5)	61	500	Rubus	1	75	0.031	0.226	0.037	0.031	0.031	0.219	0.765	0.0525	0.0367	0.225	1.126	0.0572	0.0400	0.208	1.041	0.0580	0.0406	0.244	1.221	0.0533	0.0373	0.224	1.121	0.0542	0.0379

Table 47: 132kV All Aluminium Alloy Conductors (AAAC) Overhead Line Electrical Parameters (100MVA Base) – Single and Double Circuit Tower Lines

Appendix 4 – Calculating electrical parameters

Appendix 4.1 – Resistance

Resistance is a key parameter for voltage regulation and I^2R losses as they can limit power transfer. The *Ohmic* resistance of a uniform conductor depends on its volumetric resistivity, ρ, at a defined temperature (usually measured at 20°C DC) and its cross-section area, α. The formula for calculating resistance is:

$$R = \rho \frac{l}{\alpha}$$

The resistance of an overhead line increases with temperature. The rise in resistance will depend on the temperature coefficient of the conductor material[51].

$$R_t = R_{20}\,[1 + \alpha_{20}\,(t - 20)]$$

Where R_t is the conductor positive and negative sequence resistance (R_1 and R_2) at t°C (Ω), R_{20} is the conductor resistance at 20°C (Ω), α_{20} the temperature coefficient of resistance of the conductor material at 20°C and t the conductor temperature (°C). Table 48 shows both the volumetric resistivity, ρ, and the resistance temperature coefficient per °C for the different conductor materials[52].

	Hard drawn Copper	Cadmium Copper	Hard drawn Aluminium	Aluminium Alloy	Galvanised Steel	Aluminium clad steel
R - Resistance (Ω mm^2/km)	17.71	21.769	32.5	32.5	192	84.8
α - Temperature Coefficient @ 20°C (per °C)	0.00381	0.00310	0.00403	0.00360	0.00540	0.00510

Table 48: Conductor resistivity and temperature coefficient

Zero sequence resistance depends on the circuit type (single or double) and whether or not there is an earth wire present[53]. The formulae for calculating R_0 are:

Single circuits without earth wire is:

$$R_0 = \frac{R_L}{n} + 3\frac{\mu_0}{8}\omega$$

Single circuits with earth wire:

$$R_0 = \frac{R_L}{n} + 3\frac{\mu_0}{8}\omega - 3\frac{(\frac{\mu_0}{8}\omega)^2}{Z_E}$$

Double circuits without earth wire:

[51] Based on BICC Cable Handbook – 3rd edition (p.10).

[52] Based on BICC Cable Handbook – 3rd edition (p.711).

[53] IET Short-circuit Currents – J. Schlabback p.271.

$$R_0 = \frac{R_L}{n} + 3\frac{\mu_0}{8}\omega + 3\frac{\mu_0}{8}\omega$$

Double circuits with earth wire:

$$R_0 = \frac{R_L}{n} + 3\frac{\mu_0}{8}\omega - 3\frac{\mu_0}{8}\omega - 6\frac{(\frac{\mu_0}{8}\omega)^2}{Z_E}$$

Where:

$Z_E = R_E + \frac{\mu_0}{8}\omega$

R_L: line resistance

R_E: earth wire resistance

n: number of conductors bundled together

μ_0: the permeability of space ($4\pi \times 10^{-4}$)

ω: the angular frequency

Appendix 4.2 – Reactance

The inductive reactance of an overhead line is derived from its self-inductance and the mutual inductance between the different phase conductors using the following formula:

$$X = 2\pi f L$$

Where L is the inductance per phase for a 3-phase system or the inductance of both lead and return conductor for a single phase system.

For a simple go and return two wire single phase AC system the inductance is:

$$L = 0.2\left(log_e \, {}^{d}\!/_{GMR}\right) \text{mH/km}$$

Where: d is the separation between conductor axes (mm) and GMR (also referred to D_s) the geometric mean radius of conductors (mm). GMR is ~ 0.779r for solid conductors where r is the conductor radius. Table 49 shows the GMR[54] values as a function of conductor radius for stranded conductors according to the number and size of the strands[55] [56] [57].

All aluminium or all copper conductor	
Number of Strands	**GMR**
7	0.726r
19	0.758r
37	0.768r
61	0.772r
91	0.774r
127	0.776r
169	0.776r
Solid	0.779r
ACSR	
6	0.768r
12	0.859r
18	0.776r
26	0.809r
30	0.826r
54	0.810r

Table 49: GMR Values as a function of radius r

[54] The use of GMR allows for the inductance due to flux within the conductor to be taken into consideration.

[55] Transmission and Distribution Electrical Engineering (3rd Edition) – Bayliss C., Hardy B., p.679.

[56] Alstom Protective Relays Application Guide p.55.

[57] Principles of Power Systems – Mehta V.K., Mehta R, p. 212.

For a three-phase system, the mutual effects of one conductor on another modify the formula so that the inductance per phase is:

$$L = 0.2(log_e \, {}^{GMD}/_{GMR}) \text{ mH/km}$$

Where GMD (also referred to as D_m) is the geometric mean distance between the red, yellow and blue phases (r,y,b) and represents the equivalent geometrical distance spacing;

$$GMD = \sqrt[3]{d_{ry} d_{yb} d_{br}}$$

For a three phase double circuit the formula remains the same but the GMD and GMR values are as per formulae below. However, the formula calculates the per phase inductance of two parallel conductors, therefore the inductance of an individual conductor is twice as much[58]. The equation for a double circuit therefore is:

$$L_{DC} = 2 * \left[0.2(log_e \, {}^{GMD}/_{GMR})\right] \text{ mH/km}$$

$$GMD = \sqrt[3]{D_{rb} D_{by} D_{yr}}$$

Where:

$$D_{rb} = \sqrt[4]{D_{rb} D_{rb'} D_{r'b} D_{r'b'}}$$

$$D_{by} = \sqrt[4]{D_{by} D_{by'} D_{b'y} D_{b'y'}}$$

$$D_{yr} = \sqrt[4]{D_{yr} D_{yr'} D_{y'r} D_{y'r'}}$$

D is the distance between the red, yellow and blue phases (r,y,b) on one side and red, yellow, blue phases on the other side (r’, y’, b’)

$$GMR = \sqrt[3]{D_{s1} D_{s2} D_{s3}}$$

Where:

$$D_{s1} = \sqrt[4]{D_{rr} D_{rr'} D_{r'r} D_{r'r'}}$$

$$D_{s2} = \sqrt[4]{D_{bb} D_{bb'} D_{b'b} D_{b'b'}}$$

$$D_{s3} = \sqrt[4]{D_{yy} D_{yy'} D_{y'y} D_{y'y'}}$$

D is the distance between the red, yellow, blue phases (r,y,b). D_{rr} and $D_{r'r'}$ is the self-GMD of conductor and $D_{rr'}$ is the distance between red and red. Figure 1 below shows the phase configuration of both a normal and a transposed circuit.

[58] Elements of Power System Analysis (Second Edition) – Stevenson Jr,,W. D, p. 46.

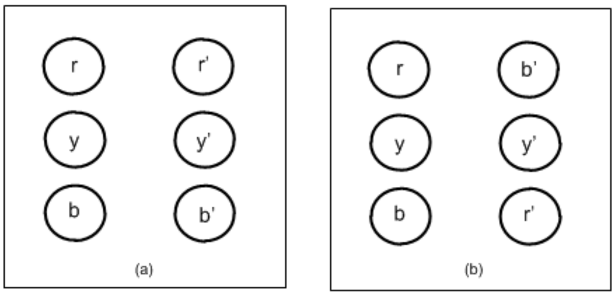


Figure 1: Double circuit conductor arrangement: (a) normal, (b) transposed

The positive and negative sequence line to neutral inductive reactance X_1 and X_2, are equal and for a frequency *f* (Hz) become:

$$X_1, X_2 = 2\pi f L * 10^{-3} \text{ ohms/km}$$

Zero sequence reactance (X_0) depends upon a number of factors including the position and materials used for earth wires, construction type and the ground resistivity. The complexity of the calculations and the assumptions that would go in them make it appropriate to use the typical ratios in Table 50[59].

Earth Wire	Overhead line	X_0/X_1	Example Construction
-	Single circuit	3.5	CE/C/37
-	Double circuit	5.5	Wood House masts w/out EW
Galvanised steel	Single circuit	3.5	Wood House masts (CE/C/37/4W) and Tower Lines with Al conductors
Galvanised steel	Double circuit	5	Wood House masts and Tower Lines with Al conductors
Non-magnetic	Single circuit	2	Wood House masts and Tower Lines with Cu conductors
Non-magnetic	Double circuit	3	Wood House masts and Tower Lines with Cu conductors

Table 50: X_0/X_1 Ratios

Note:

Two three-phase circuits that are identical in construction and electrically in parallel have the same inductive reactance. The inductive reactance of the “single equivalent” circuit however is half that of each individual circuit considered alone if the distance between the two is significant and therefore there is negligible mutual inductance between them. The inductive reactance is lowered if individual conductors of a phase are separated as widely as possible and if the distances between phases are kept small (a). Conversely, inductance increases if the distance reduces (b) to the point where reactance would be similar to that of a

[59] Transmission and Distribution Electrical Engineering (3rd Edition) – Bayliss C., Hardy B., p.680.

single circuit operating on its own (c)[60]. The inductance of each individual conductor is twice that of the single circuit equivalent.

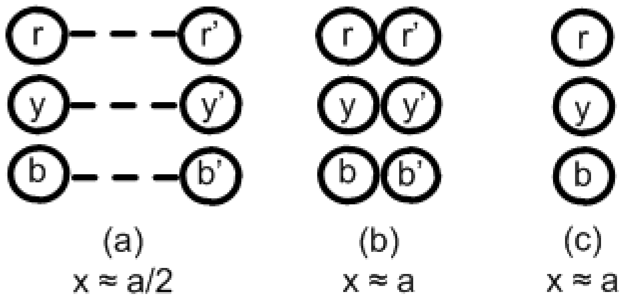


Figure 2: Inductive reactance of adjacent conductors

[60] Elements of Power System Analysis (Second Edition) – Stevenson Jr,,W. D, p. 45.

Appendix 4.3 – Capacitance

Capacitance exists among conductors due to their potential difference. When calculating capacitance, the capacitance between conductor to neutral is considered instead of capacitance from conductor to conductor. Since the potential of the mid-point between conductors is zero, the potential difference between each conductor and the ground/neutral is half the potential difference between the conductors. The formula for calculating capacitance to neutral is[61 62]:

- Single phase two-wire system:

$$C_N = \frac{2\pi\varepsilon_0}{\ln\frac{d}{r}}$$

- Three phase system (single circuit):

$$C = \frac{2\pi\varepsilon_0}{\ln\frac{GMD}{r}}$$

- Three phase system (double circuit):

$$C = \frac{2\pi\varepsilon_0}{\ln\frac{GMD}{2r}}$$

Where d is the distance between conductors and GMD the Geometric Mean Distance between conductors (calculated as per inductance for both single and double circuits) and ε_0 the permittivity of free space (8.8542 x10^{-12}).

For both single and double circuit circuits with no earth wire, if the distance between conductors is not comparable to the height of the conductors above earth, the effect on the value of capacitance of line to earth is negligible. On the contrary, for circuits with an earth wire, the earth wires must be taken into account when calculating the conductor to earth capacitance. However, since the capacitance of an overhead line is a lot less than that of cables[63], its overall impact is minimal and therefore an estimation as opposed to an exact calculation can be used. The following approximation factors can be used[64 65]:

Circuits without earth wire:

$$C_0 = 0.6\ x\ C_1$$

Circuits with earth wire:

$$C_0 = 0.7\ x\ C_1$$

[61] Electrical Power System Design – Deshpande M. V, p. 23.

[62] Principles of Power Systems – Mehta V.K., Mehta R, p. 222.

[63] An 11kV 100mm^2 Aluminium overhead has 50 times less capacitance than a 300mm^2 T-XLPE cable, even though they have comparable ratings.

[64] ABB Pocket Book – Switchgear Manual (10th revised edition) p. 94.

[65] Groupe Schneider, Cashier Technique n° 190 – Ferroresonance p. 21.

The susceptance (B) is the imaginary part of admittance. It is calculated as the reciprocal of the capacitive reactance:

$$B = \frac{1}{X_C} = 2\pi f C$$

From susceptance, the charging current can therefore be calculated as:

$$I_c = BV_{PE} = 2\pi f C_{PE}$$