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CONDUCTOR RATINGS IN
ESKOM**

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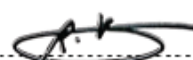
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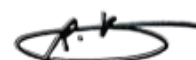
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Executive Summary

On 29 September 2015, Eskom approved the line conductor ratings tables for use in Transmission and Distribution Grids. These ratings were calculated after a large weather database was compiled, and new Mathcad thermal rating calculation software was developed to replace the earlier Monte Carlo methods and Visual Basic tools with algorithms as described in Cigre in the early 1990's.

More recently, Eskom also approved the specification for "Phase Conductor for Eskom Overhead Lines" document number 240-152844641, whereby a range of additional ACSR and AAAC conductors were added. The ratings for these conductors were added through the use of the same weather database and the Mathcad program that was used for the previous issue.

Through collaboration with Eskom Distribution, it was discovered that the ratings of some of the copper conductors that were already listed had to be re-calculated due to the fact that hard-drawn copper properties differ slightly from soft-drawn copper which had been erroneously used up until 2015. A few conductors in use in Distribution were found to be missing from this document's tables but used by Eskom, and had to be addressed by adding these.

This document therefore aims to bring the ratings tables up to date for the new IEC range of AAAC and ACSR conductors, as well as for the copper conductors, and a few traditional ACSR and AAAC conductors that are in use in Distribution which had not been listed in this document before.

A tandem document on the application of this guideline to National Control Centre and Protection Department for the operation of lines in terms of thermal ratings will be developed in 2021. Eskom Distribution will be included in the process. This document will be valuable when a catastrophic event arises where a line(s) are already running under contingency conditions.

1. Introduction

The power transfer on transmission lines affects the sag of the conductor and hence the height of the conductor above the ground. This in turn affects the safety of the line. The determination of the allowable power transfer is thus not only a function of the properties of the conductor but also of the safety to the public. It is thus essential that the designers are aware of the factors that affects the safety of a transmission line as well as the types of accidents or factors that are pertinent to the utility.

In the past, Eskom used what is referred to as the Deterministic method for calculation of the conductor thermal rating or ampacity by using conservative ambient conditions. These conservative ambient conditions of 40 °C ambient temperature, 1 120 W/m² solar irradiation and 0,44 m/s wind speed were used, together with equations derived in the 1940's by Hutchins and Tuck and described in a book by Butterworth, to determine the conductor current rating.

Ratings were calculated for normal and emergency conditions at 75 °C and 90 °C. The lines were then template at 50 °C according to an internal Eskom directive, EED 15/6/1-1 1970. This means that if the conductor temperature reached 50 °C, the height of the conductor above the ground would be at the height prescribed by law. It follows that if the line was operated at the rated normal current and the severe ambient conditions were present, the conductor temperature would be near 75 °C, which would result in the line being under clearance, in terms of legislation. The directive stated that the probability of this occurring was so low that it was acceptable to template at 50 °C and determine the current rating for 75 °C and 90 °C. This probability was not quantified.

This practice served Eskom well for almost thirty years and there were no known incidents of a contact occurring due to the thermal limit being exceeded. However, in today's economic environment it is necessary to use assets more efficiently and on power lines costs can be deferred or saved by finding ways to operate the lines closer to the safe design limits.

One way to do this is to provide the means to calculate the line ratings at different template temperatures, which, was not possible using the previous directive.

The existing practice of applying probabilistic conductor ratings served Eskom from the 1990's until 2008, when this latest conductor-rating standard was completed in order to update the probabilistic ratings with the latest improvements available.

This document provides the means to calculate the line ratings at different template temperatures. It also quantifies the probability of an unsafe condition arising associated with the rating and keeps this constant for conductors of a similar type.

It is important to note that the probabilities applied are based on the present practices so that if the line is utilised at a higher temperature, the probability of an unsafe condition arising is no more than the probability designed for at present. The lines are therefore just as safe as in the past albeit they are operating at a higher temperature with a higher rating.

2. Supporting clauses

2.1 Scope

The document covers the application of the thermal ratings for the different template temperatures listed (50, 60, 70 and 80 °C). The weather data in South Africa, which represents countrywide data, not including data sampled at airports, was used to derive the applicable ratings. The application of the table by planners, designers and operators is also discussed, and an example of using local weather data for a specific area to enhance ratings is included.

The generic ampere values listed in this document guides the user for general weather conditions across South Africa by including the above representative weather data set as a basis. Specific situations will need to be studied on a case-by-case basis if these ratings are not adequate.

The use of local conditions to determine the likely increase in ampacity by using real time monitoring on certain lines is not covered in this document.

2.1.1 Purpose

This document lists the conductor thermal rating of all conductor types used on the Eskom Transmission and Distribution Grids against the line template temperature, ranging from 50, to 60, 70 and 80 °C respectively.

For each conductor, there are three ratings described for each temperature range, namely

Conductor rating	Applicability
Rate A	All lines in service – healthy system (old “Normal” or 75 °C rating) *
Rate B	N-1 contingency – could last for days or weeks (old “Emergency or 90°C rating”)*
Rate C	15 Minute time limited rating

*no time limit set – assuming a damaged power line will be restored within weeks.

Design Engineers, Grid Planners and System Operator staff can use this document to calculate the overhead power line conductor ampere or power ratings. This document lists the current rating in Ampere for 50 °C, 60 °C, 70 °C and 80 °C for normal and emergency situations respectively (Rate A and Rate B).

For short-term applications where the time is strictly limited to a maximum of 15 minutes, Rate C values can be applied.

2.1.2 Applicability

Existing and new Power lines using conductors in the tables, and located within the geographical boundaries of South Africa, can be rated according to the values given in this document.

This document shall apply throughout Eskom Holdings Limited Divisions.

2.2 Normative/informative references

Parties using this document shall apply the most recent edition of the documents listed in the following paragraphs.

2.2.1 Normative

- [1] ISO 9001, Quality Management Systems.
- [2] Cigre ALTERNATING CURRENT (AC) RESISTANCE OF HELICALLY STRANDED CONDUCTORS, TB345, April 2008
- [3] EED 15/6/1-1:1970, Title Thermal limits of transmission line and busbar conductors.
- [4] ERA Publications OT/4:1953, Electrical characteristics of overhead lines (S. Butterworth)
- [5] Swan, J. November 1995. Determination of conductor ampacity - A probabilistic approach. A dissertation submitted to the School of Electrical Engineering at Vaal Triangle Technicon South Africa, in fulfilment of the requirements for the Magister Technologiae Degree.
- [6] Cigre, GUIDE FOR THERMAL RATING CALCULATIONS OF OVERHEAD LINES, 601, Working group B2.43, 2014

2.2.2 Informative

- [7] Eskom, Phase conductor for Eskom Overhead lines, Doc 240-152844641, 2020.
- [8] Aberdare Overhead Conductor Catalogue (www.Aberdare.co.za)
- [9] Working Group 12 Cigre:1992, The Mathematical model for evaluation of conductor temperature in the steady state and the application thereof (Electra number 144 October 1992 pages 107 to 125).
- [10] Cigre, Thermal behaviour of Overhead Conductors, 207, Working Group 22.12, August 2002

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- [11] Working Group 12 Cigre:1996, Probabilistic determination of conductor current rating (Electra Number 164 February 1996 pages 103 to 119).
- [12] Probabilistic conductor ratings revised for use in Eskom, AA Burger, Dr D Muftic, Mr RG Stephen, August 2008 (Eskom Research Report issued by Trans-Africa Projects)

2.3 Definitions

2.3.1 General

Definition	Description
Ampacity	The ampacity of a conductor is that current that will meet the design, security and safety criteria of a particular line on which the conductor is used.

2.3.2 Disclosure classification

Controlled disclosure: controlled disclosure to external parties (either enforced by law, or discretionary).

2.4 Abbreviations

Abbreviation	Description
Eskom DX	Eskom Distribution Division
Eskom TX	Eskom Transmission Division
SCOT	Steering Committee Technical

2.5 Roles and responsibilities

Lines Engineering Manager, who is also the Chairman of the SCOT for overhead lines, authorizes and supports the document and from there it is registered and distributed throughout Eskom for implementation.

2.6 Process for monitoring

It is assumed that all operators, design engineers and consultants will use these conductor ratings pertaining to overhead power lines in South Africa.

2.7 Related/supporting documents

Document **240-100176272** is replaced by this document.

3. Overhead Line Conductor Thermal Rating Calculation

3.1 Eskom historical involvement in calculation of conductor ampacity

In 2009, Eskom participated in and developed a Mathcad software tool which was used to calculate the ratings that were updated in the 2015 version of the ratings document. At this time, most of the heating and cooling components which form part of the steady state heat balance equation were updated from their outdated definitions as listed in the 2002 Cigre Brochure 207.

The magnetic heating model was improved by including the steel core properties of ACSR conductors based largely on the well-known work done by Vincent Morgan. As covered by Cigre TB345 in 2008.

In 2016, after further Eskom participation and collaboration, Cigre published TB601 "GUIDE FOR THERMAL RATING CALCULATIONS OF OVERHEAD LINES" which focused on refinements of the convective and radiated cooling components of the heat balance equation.

Eskom already implemented all of the above enhancements in its 2009 version of the Mathcad software program, and hence, the 2009 ratings need not be re-calculated. Therefore, at present, only new conductors are being added and the hard-drawn copper properties were used to re-calculate the ratings of copper conductors used by Eskom Distribution.

3.2 Deterministic and Probabilistic Conductor Rating Calculation Methods

There are two methods of calculating conductor ampacity tables; the deterministic approach and the probabilistic approach.

The deterministic approach assumes certain bad cooling conditions (low wind speed, high ambient temperature, etc.) and calculates the current that would result in the design temperature of the line being reached. The line templating or design temperature is that temperature, at which the height of the conductor above the ground is the minimum permissible. The deterministic approach has been used by utilities for a number of years. It is a quick and simple method. Bad cooling conditions are assumed and the current that will result in the line design temperature being achieved is calculated. The drawback is that the method does not address the safety or the relationship between safety and the power transfer capability.

Eskom is at present designing and operating its lines and power systems based on, inter alia, the allowable current (or ampacity) that can flow down the line. This current was previously calculated using a deterministic approach with assumed bad cooling conditions. It is assumed that by limiting the current, the safety criteria will be met and the line will not contravene any regulations.

It is known however, that conditions may result at some stage in the conductor exceeding the line design temperature causing the line to be under clearance. What is needed therefore is the quantification of the safety aspect of the design.

The probabilistic approach uses the actual weather data and conditions prevailing on the line or in the area to determine the likelihood or probability of a certain condition occurring. Such a condition could be, for example, the conductor temperature rising above the design temperature. These methods have been developed to include a measure of safety of the line. This can be used as a means of comparison of practices between utilities in all countries.

There may be a problem in obtaining accurate low wind speed data. Very low wind speeds (less than 1,0 m/s) are not recorded accurately by cup anemometers generally used by national weather services. Data received from these services may, therefore, be of limited use.

3.2.1 Method of Probability of an Accident Occurring

The first is the method whereby the probability of an accident occurring can be quantified. The benefits of this method are that an absolute measure of safety is achieved. The drawback is that the nature of the parameters (later described in 5.2.1) is extremely difficult to determine. In addition, the correlation between the parameters, for example, the weather parameters, need to be determined.

3.2.2 Method of using spot measurement of weather data and line current to determine temperature

The second method uses the existing weather data to determine the temperature of the line conductors for a given current flow. The amount of time that the temperature exceeds the line design temperature can be determined for each current level. The utility can then decide on the current level to use based on the percentage of excursion or "exceedance". The advantage of this method is that it is relatively easy to determine the percentages and decide on a level by which to operate. The disadvantage is that there is no way of determining the difference in safety (to the public) between, for example, the 5 % and 6 % excursion levels.

An adaptation of this method is to simulate the weather data and the current flow to determine the cumulative distribution of the conductor temperature as a function of current. This curve could be used to determine the current and excursion level.

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3.2.3 Method of simulating safety under a transmission line using all factors

The third approach is to simulate the safety of a transmission line by incorporating all the factors that affect the safety of a line. From this method, a measure of safety can be developed whereby the practices in different countries can be compared on an objective basis. The advantage of this method is that all factors are considered. The variation of the occurrence of objects under the line e.g. a traffic pattern can be related to the safety of a line. Designers can use a wider range of methods to increase the thermal rating of the line not generally used before. An example of this is the reduction of surge magnitudes or the number of surges per year can be used to increase the current carrying capacity of a line.

By using the measure of safety, system planners and line designers are in a position to determine the consequences of decisions in an objective way, rather than a subjective way.

Similarly, System Operators, by using the measure of safety together with data from a real time monitoring system, could operate transmission lines at higher than rated currents during emergencies.

Utilities worldwide would be in a position to determine the safety of their lines in relation to other utilities.

This standard deals exclusively with the absolute probability method, as this method is the one preferred for the generation of ampacity tables.

3.2.4 Determination of the absolute probability of an unsafe condition arising

Research to date has primarily being confined to attempts at determining the probability of an unsafe condition arising. This is determined by ascertaining the probability of each factor occurring and multiplying the probabilities.

This is represented as:

$$P(\text{acc}) = P(\text{CT}) \times P(\text{I}) \times P(\text{obj}) \times P(\text{surge}) \text{ (Stephen, 1991)}$$

Where,

$P(\text{acc})$ is the probability of the accident arising.

$P(\text{CT})$ is the probability of a certain temperature being reached by the conductor and is calculated from existing weather conditions, conductor types and an assumed current.

$P(\text{I})$ is the probability of the assumed current being reached and is determined from the actual current being measured on a system.

$P(\text{obj})$ is the probability of the electrical clearance being decreased by an object or person.

$P(\text{surge})$ is the probability of a voltage surge occurring in the line and may be determined from fault records kept by the power utility as well as simulations on switching surge overvoltages on the system. Should the surge occur simultaneously with the object being under the line, the likelihood of a flashover is increased.

Each of the above is determined independently.

$P(\text{CT})$ used to be determined by the Monte Carlo simulation technique sampling from distributions of ambient temperature, wind speed, wind direction and solar irradiation to calculate the probability of a certain temperature being reached given a current transfer. The ambient temperature, solar irradiation, wind speed and wind direction are sampled independently to form a set of parameters from which the temperature of the conductor is determined.

The problem with this method was that it assumed there is no correlation between weather parameters or the current, object and surge occurrences. This may not be correct in all cases. The correlation between the individual weather parameters, as well as the weather parameters, the surge occurrences and objects being under the line, must be ascertained.

This problem is now solved by determining P(CT) from a large sample of actual recordings of ambient temperature, wind speed and wind direction taken at the same time. The SA Weather Service do not record solar data at a large number of stations, and global solar irradiation was therefore calculated theoretically as a function of the day and time of the day for the locations from where weather data was sourced.

3.3 Application of the absolute method in Eskom

In system planning and design, overhead line transmission capacity is a parameter of major importance. It is therefore necessary to have exhaustive information regarding the factors affecting this capacity in order to be able to design a transmission system under the best possible technical and economic conditions.

The power transfer capability of transmission lines are limited by economic, physical and statutory constraints. Conductor current and temperatures generally determine the amount of power that can be transmitted over a given circuit. The maximum temperature at which a conductor can safely operate is determined by:

- a) permissible sag, that is governed by statutory requirements;
- b) annealing and long term creep, and;
- c) the reliability of joints and fittings.

In addition, limits imposed by temperature, line transfer limit or losses may limit the load capability of specific transmission lines.

Because of the economic pressures to increase the current carrying capacity of both existing and planned overhead lines, there is a growing interest in using probabilistic methods, which take into account the variability of the stochastic nature of the meteorological parameters.

The probability of a certain load current, that will result in the template temperature being met, is equal to the product of the individual probabilities of the weather conditions and conductor surface temperature (Swan1995).

$$P(T_c) = P(I) \times P(T_a) \times P(GSR) \times P(WS) \times P(WD) \implies P(I) = P(T_c) / (P(T_a) \times P(GSR) \times P(WS) \times P(WD))$$

where

P(T_c) is the probability of a conductor temperature;

P(I) is the probability of a current;

P(T_a) is the probability of an ambient temperature;

P(GSR) is the probability of global solar radiation;

P(WS) is the probability of wind speed; and

P(WD) is the probability of wind direction.

The weather model was constructed from historical hourly weather data from six weather stations in South Africa. The weather stations were selected to avoid airport data since research findings indicated that airport weather data represent cooler temperatures and higher wind speeds. The data totals 77 years of hourly data sets, from which a random set of data was selected to calculate not less than 1500 values of P(CT) for each conductor considered at 50, 60, 70 and 80 °C respectively.

City	Number of years of Data	Years of data
Beaufort West	12	1995 -2006
Taung (Vryburg)	9	1997 - 2006
Upington	14	1993 - 2006
Springbok	15	1992 - 2006
Komatidraai (Komatipoort)	13	1994 - 2006
Polokwane (Pietersburg)	14	1993 - 2006
	77	

All wind speed data below 1 m/sec was modified by using a transfer function derived from parallel measurements at the same location using the 3D ultrasonic anemometer alongside the propeller anemometer used by the SA Weather Services. In this manner, the inaccurate response of the propeller anemometer could be rectified to avoid conservative values for P(CT) being calculated. Please refer to Annex F for more information.

A range of conductor current values are generated from the above that will result in the template temperature being met. In order to identify the optimal current from the range, it is necessary to identify conditions that may lead to a possible dangerous condition. Typical high-risk factors are 1) with high traffic density road crossings. 2) the possibility of a flashover from the conductor to an object underneath the conductor. The main factors that may cause a flashover are:

- a vehicle, at least 4,65 m high, underneath the conductor;
- full load current;
- weather conditions that together with full load current will result in the conductor surface temperature being equal to the template temperature;
- maximum system voltage; and
- an impulse, switching or as result of lightning, that will transiently raise the system voltage to at least 2 per unit (p.u).

The above are assumed to be occurring independently. Therefore, the probability of an unsafe condition or accident is equal to the product of the individual probabilities (Swan, 1995).

$$P(\text{acc}) = ((P(\text{Ta}) \times P(\text{GSR}) \times P(\text{WS}) \times P(\text{WD}))/P(\text{Tc})) \times P(\text{OBJ}) \times P(\text{S.I}) \times P(\text{U.max}) \times P(2,5\text{p.u})$$

Where

P(acc) is the probability of an unsafe condition occurring, calculated for the Eskom design practice prior to 1987 i.e. 75 °C conductor thermal rating and 50 °C template temperature (set at 1.2 in 1 million, more or less in line with Koeberg Nuclear Power Station risk of failure);

P(OBJ) is the probability of an object under the line, based on the N1 between Johannesburg and Pretoria traffic patterns i.e. 800 vehicles per hour of which 40 % are trucks with a maximum height of 4,2 m;

P(S.I) is the probability of switching impulse occurring, calculated based on transmission performance database;

P(U.max) is the probability of maximum system voltage, assumed to be 1; and

P(2.5p.u) is the probability of the surge magnitude being 2 p.u based on a simulation representative line in the system.

3.3.1 Rate A derived from 75°C Deterministic ratings

For the purpose of generating the table the probability of an unsafe condition occurring was calculated for the Eskom design philosophy prior to 1987. With this philosophy, the conductor was thermally rated for a 75 °C electrical rating, but the line template temperature was at 50 °C. The probability of an unsafe condition was then kept constant and the ratings at different temperatures were then calculated. The table of ampacity values will therefore not increase the Eskom operational risk. For example, the probability for Wolf conductor at 370 A at a template temperature of 50 °C for normal operation (Rate A) was then calculated at 9.83%. This probability was kept constant in order to calculate the rating of Wolf conductor at different template temperatures. This method was in turn used for other conductors. The probability used for Wolf conductor was used for all double layer ACSR conductors.

3.3.2 Rate B derived from 90°C Deterministic ratings

A similar method was used for other conductor configurations. The same approach was used for the Rate B ratings in that the probability which is 5 times higher at 49.11%, was calculated for the present emergency conditions and kept constant for the different template temperatures. Additional to the Rate A and Rate B ratings, which are both not constrained by the amount of time these ratings can be applied, a third rating, called Rate C, which is limited to a maximum period of 15 minutes of application, was introduced. The risk level for Rate C is 63% above that of Rate B, and it uses the adiabatic formulas published in Cigre to take into account the thermal time constants of aluminium, steel, aluminium alloys and copper respectively. Heavy conductors have significantly increased ratings because of higher mass and thermal inertia. For Rate C calculation, 25 minutes was assumed for solving the adiabatic equation, but a 15 minutes time limit was applied conservatively for all conductors with a square aluminium alloy area of 400 mm² or more.

3.3.3 Rate C for time-limited emergency conditions

Rate C is the term given to the emergency rating permitted for lines in the Eskom network. It is for a duration of 15 minutes and is aimed at providing the operator with a short term high current rating that may allow for rectification of the grid avoiding load shedding.

The determination of Rate C was developed by D. Muftic and R. Stephen with the assistance of Arthur Burger in 2008 prior to finalizing the 2009 standard. The method is covered here so that future engineers can understand the derivation of the rating.

In determining the rate C it was first attempted to determine the current that would result in the same probability of an unsafe condition arising as the rate B but with a far lower probability of occurrence. The emergency situation is likely to be realized once or twice per annum for a period of around 15-30 minutes. Taking this into account it was found that the current that would result in a probability of unsafe condition arising being the same as rate A or rate B was excessive and would damage the conductor.

A different approach was therefore adopted.

From Cigre TB207, page 11, the following can be used:

$$t = \frac{-mc\theta_m}{I^2 R_{ac} + P_s} \ln \left(\frac{\theta_m - \theta}{\theta_m - \theta_1} \right) \quad (25)$$

where

$$\begin{aligned} R_{ac} &= \text{ac resistance per unit length at ambient temperature} \\ \theta &= T_{av} - T_a = \text{average temperature rise of conductor} \\ \theta_1 &= T_{av1} - T_a = \text{initial average temperature rise of conductor at time } t_1 \\ \theta_m &= T_{avm} - T_a = \text{asymptotic average temperature rise of conductor} \end{aligned}$$

Fig. 1 shows the heating characteristic for a conductor after a step increase in current.

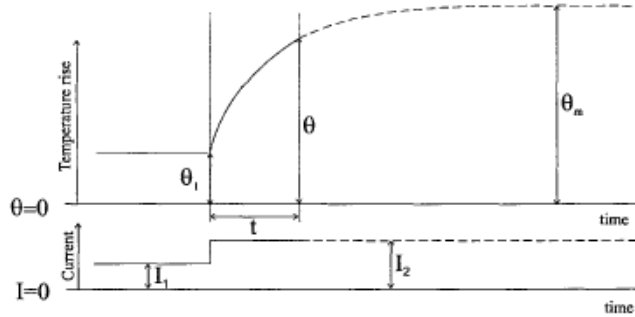


Fig. 1

The thermal time constant τ_h is the time interval for the temperature rise of the conductor to reach 63.2 % of its asymptotic (steady-state) value θ_m . The thermal time constant is given by:

$$\tau_h = \frac{mc\theta_m}{I^2 R_{ac} + P_s} \quad (26)$$

The time constant for a conductor in dynamic state is considered the time it takes for the conductor to reach 63% of steady state temperature with a step change in current. It was therefore decided that as an initial estimate of the rate C, the exceedance used would be 1.63 times rate B.

Using this exceedance value the initial estimate for rate C is calculated Initial.

Using this current the steady state temperature is determined. This is the temperature assuming the input current passing through the conductor initially is constant. The weather conditions chosen are the same as for those stated in EED 1970, that is 0,44m/s, 1120w/m², and 40°C ambient temperature. Altitude is taken at 1500m to be conservative. This gives a temperature $\theta_{m_{initial}}$.

Using this $\theta_{m_{initial}}$ temperature, a current (I_{RateC}) is calculated that will cause the conductor to reach this temperature in 15 minutes with an initial temperature calculated from rate B continuously being applied with the ambient conditions stated above. Note that for larger conductors a time period of 25 minutes was used to ensure that the equation can be solved, but the rating applies only to 15 minutes since the equations cannot solve unless more than 15 minutes are allowed.

This current is then the rate C.

3.3.4 Opportunities to re-rate specific power lines using weather data from the line route

Power lines in service may be further optimized using hourly weather data and the actual load profile of the line. The uprating of lines with this method would not result in the same increase in power transfer capacity that would be possible with real time monitoring. It is however, less costly, requires a once-off resource, and may potentially increase the transfer capacity up to 25 %.

The potential increase of 25% is in most cases sufficient to delay capital expenditure. In some cases, capital expenditure may even be deferred indefinitely. The potential increase in power is dependent on a number of factors i.e. the terrain, the original design criteria, survey tolerances, equivalent spans etc. The successful uprating of a line can only be achieved once the impact of all these factors has been accessed in terms of the safety and reliability of the line in question.

When the new ampacity values are used for the planning and design of new lines, it is of vital importance that the template temperature and conductor thermal rating are the same. If the template temperature and conductor thermal rating are different the probability of an unsafe condition $P(\text{acc})$ will not be the same as the calculated values in the tables in this document. The operational risk to Eskom and the safety to the public will therefore be adversely affected. Please note that no lines should be template above 80 °C without in depth investigation on the annealing of the conductor and condition of joints.

The benchmark template temperature value of 50°C will be used unless it can be clearly demonstrated that 60°C or higher values such as 70°C or 80°C must be used to prevent unjustified additional capital expense.

3.4 Example of Calculating AC and HVDC Ratings for Zambezi ACSR Conductor

Under steady state conditions, the heat gain and heat loss of a conductor is equal and are described by the following components [9]

Heat gain = heat loss

$$P_J + P_M + P_S + P_i = P_c + P_r + P_w$$

where

P_J	= Joule heating
P_M	= magnetic heating
P_S	= solar heating
P_i	= corona heating
P_c	= convective cooling
P_r	= radiative cooling
P_w	= evaporative cooling

The Joule heating component is dominated by the resistance of the conductor and the current passing through it and exists for both the AC and DC situations. However, P_M represents the magnetic losses due to flux linkage from the aluminium layers with the internal steel core due to the opposing directions of the aluminium layers (transformer effect). In the case of DC current, this transformer effect is absent due to there being no time-varying flux variations.

The ratings for Zambezi for AC and DC reflects this minor effect of magnetic heating that is absent for DC current and hence can be expected to produce a marginally increased current thermal rating.

Conducting Area mm ²	Conductor	Temp	Rate A	Rate B	Rate C
565.4	ZAMBEZI (DC)	50	852	1234	2044
565.4	ZAMBEZI (DC)	60	1016	1417	2235
565.4	ZAMBEZI (DC)	70	1143	1567	2396
565.4	ZAMBEZI (DC)	80	1250	1688	2564
565.4	ZAMBEZI (AC)	50	841	1220	2023
565.4	ZAMBEZI (AC)	60	1000	1407	2220
565.4	ZAMBEZI (AC)	70	1124	1556	2396
565.4	ZAMBEZI (AC)	80	1229	1691	2352

3.5 Example of Absolute Probabilistic Ratings using the tabled ampere ratings**3.5.1 Example 1 – Determine the MVA Rating of an existing 400kV line:**

Line voltage = 400kV

Conductor type – Dinosaur ACSR

Conductors in bundle - 3

Template temperature = 50 °C

Solution:

Rate A = 938 A (per Dinosaur Conductor)

Maximum phase current = 938 A x 3 = 2814 A

Phase voltage = $400\,000/\sqrt{3} = 230\,940\text{ V}$

Rate A 3 phase VAR's = 2814 A x 230940 V x 3 phases = 1949.59 MVA

For rate B, the same method applies – and can be scaled:

Rate B = 1380A

Rate B 3 phase VAR's = Rate A Vars X 1380/938 = 2868.27 MVA

3.5.2 Example 2 – Determine the size of single conductor to meet 70 °C thermal rating for 100 MVA rating of a 132kV line:

MVA rating = 100 MVA

Line Voltage = 132 kV

Phase Voltage = $132/\sqrt{3} = 76.21\text{ kV}$ Phase Current = (MVA Rating / (phase voltage))/3 = $(100\,000\,000/76\,210)/3 = 438\text{ A}$ **Solution 1 – ACSR**

If a single ACSR conductor at 70 °C must be used, the smallest conductor suitable for the task is found to be Tiger ACSR:

131.2	TIGER	50	322	466	697
131.2	TIGER	60	393	535	775
131.2	TIGER	70	444	593	845
131.2	TIGER	80	485	643	903

Figure 1: Tiger ACSR Ratings**Solution 2 – AAAC**

If a single AAAC conductor at 70°C must be used, the smallest conductor suitable for the task is found to be Ash. In fact, even at 60 °C, this conductor will be capable of performing the task.

180.7	ASH	50	381	548	801
180.7	ASH	60	463	630	890
180.7	ASH	70	523	700	964
180.7	ASH	80	574	762	1030

Figure 2: Ash AAAC Ratings

4. Authorization

This document has been seen and accepted by:

Name and surname	Designation
Prashant Mathuradas	Electrical Engineer – PDE – Lines Engineering Services
Riaan Smit	Chief Engineer -
Arthur Burger	Chief Engineer - PDE – Lines Engineering Services
Riaz Vajeth	Senior Manager PDE – Lines Engineering Services

5. Revisions

Date	Rev	Compiler	Remarks
Feb 2021	1	Prashant Mathuradas / Arthur Burger	Added the new IEC conductors on the Eskom buying list, corrected hard-drawn copper conductor ratings, and added a few conductors used by Eskom Distribution that were not in the list. 240-152844641 – Phase conductor standard for overhead lines
Sept 2015	2	Sumeet Ramandh	Converted to new format, prepare for adding new range of IEC conductors and some Distribution conductor updates done by Riaan Smit
Jan 2010	1	Arthur Burger	Increased the total probability of an accident from 1 in 1 million to 1.2 in 1 million to avoid reduced ratings for frequently used conductors in Eskom Distribution Network. Note that the probability of an accident is still significantly below the old 75 ^o C and 90 ^o C deterministic risk levels.
Nov 2008	0	Arthur Burger	Improved accuracy of calculations, bigger weather database, introduction of Rate A, B and time limited Rate C. Added list of al 132, 220, 275 and 400kV lines with conductor and equipment ratings List all changes to the document, as well as authorities for these changes.

6. Development team

The following people were involved in the work for the development of this document:

- Riaan Smit
- Prashant Mathuradas
- Raeesa Khan
- Arthur Burger

7. Acknowledgements

Rob Stephen for mentorship and support in this field.

Riaan Smit for highlighting some additional conductors that are used in Eskom Distribution, and for double checking ratings.

Annex A – AAAC Conductor Ampere RatingsRho alloy = 0.325 ohm.mm²/m, alpha = 0.0036 per °C

Conducting Area mm ²	AAAC	Temp	Rate A	Rate B	Rate C (15min)
23.8	ACACIA	50	108	153	187
23.8	ACACIA	60	129	176	213
23.8	ACACIA	70	145	194	235
23.8	ACACIA	80	157	210	253
42.2	AAAC 35	50	158	216	268
42.2	AAAC 35	60	188	248	302
42.2	AAAC 35	70	209	275	333
42.2	AAAC 35	80	230	299	360
71.7	PINE	50	219	302	386
71.7	PINE	60	261	346	432
71.7	PINE	70	293	385	474
71.7	PINE	80	320	418	512
118.9	OAK	50	297	417	564
118.9	OAK	60	350	479	636
118.9	OAK	70	391	530	698
118.9	OAK	80	432	575	747
180.7	ASH	50	381	548	801
180.7	ASH	60	463	630	890
180.7	ASH	70	523	700	964
180.7	ASH	80	574	762	1030
210.9	ELM	50	424	625	908
210.9	ELM	60	514	712	1019
210.9	ELM	70	581	783	1126
210.9	ELM	80	637	845	1210
303.2	SYCAMORE	50	549	775	1302
303.2	SYCAMORE	60	639	888	1476
303.2	SYCAMORE	70	725	981	1612
303.2	SYCAMORE	80	787	1066	1686
363.0	IEC315 AAAC	50	573	834	1443
363.0	IEC315 AAAC	60	686	959	1592
363.0	IEC315 AAAC	70	772	1064	1731
363.0	IEC315 AAAC	80	848	1151	1848
460.0	IEC400 AAAC	50	676	988	1714

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Conducting Area mm ²	AAAC	Temp	Rate A	Rate B	Rate C (15min)
460.0	IEC400 AAAC	60	813	1133	1896
460.0	IEC400 AAAC	70	911	1252	2049
460.0	IEC400 AAAC	80	994	1362	2150
479.0	YEW	50	707	1030	1598
479.0	YEW	60	842	1183	1786
479.0	YEW	70	948	1306	1943
479.0	YEW	80	1037	1413	2081
518.0	IEC450 AAAC	50	734	1074	1695
518.0	IEC450 AAAC	60	883	1233	1887
518.0	IEC450 AAAC	70	989	1363	2054
518.0	IEC450 AAAC	80	1078	1481	2190
575.0	IEC500 AAAC	50	790	1160	1874
575.0	IEC500 AAAC	60	945	1332	2071
575.0	IEC500 AAAC	70	1063	1480	2248
575.0	IEC500 AAAC	80	1161	1601	2408
645.0	IEC560 AAAC	50	850	1254	2092
645.0	IEC560 AAAC	60	1018	1441	2300
645.0	IEC560 AAAC	70	1145	1601	2494
645.0	IEC560 AAAC	80	1248	1737	2651
725.0	IEC630 AAAC	50	918	1364	2286
725.0	IEC630 AAAC	60	1102	1575	2516
725.0	IEC630 AAAC	70	1237	1744	2744
725.0	IEC630 AAAC	80	1351	1887	2946
817.0	IEC710 AAAC	50	997	1489	2579
817.0	IEC710 AAAC	60	1202	1718	2843
817.0	IEC710 AAAC	70	1351	1903	3087
817.0	IEC710 AAAC	80	1475	2059	3312
921.0	IEC800 AAAC	50	1093	1622	3020
921.0	IEC800 AAAC	60	1318	1863	3321
921.0	IEC800 AAAC	70	1480	2066	3561
921.0	IEC800 AAAC	80	1611	2244	3785

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Annex B – AAC Conductor Ampere RatingsRho alloy = 0.028264 ohm.mm²/m, alpha = 0.00403 per °C**AAC Conductors**

Conducting Area mm ²	AAC	Temp	Rate A	Rate B	Rate C (15min)
157.62	Hornet	50	357	510	706
157.62	Hornet	60	427	584	790
157.62	Hornet	70	478	647	863
157.62	Hornet	80	524	700	923
363.0	BULL	50	1150	1654	3046
363.0	BULL	60	1365	1900	3325
363.0	BULL	70	1517	2117	3526
363.0	BULL	80	1660	2291	3736
374.5	CENTIPEDE	50	695	975	1489
374.5	CENTIPEDE	60	816	1121	1653
374.5	CENTIPEDE	70	913	1242	1789
374.5	CENTIPEDE	80	1002	1349	1909

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Annex C – ACSR Conductor Ampere Ratings

Rho steel = 0.138 ohm.mm²/m, alpha = 0.0045 per °C Rho alloy = 0.028264 ohm.mm²/m, alpha = 0.00403 per °C

Conducting Area mm ²	ACSR	Temp	Rate A	Rate B	Rate C (15min)
6.7	BANTAM	50	57	79	96
6.7	BANTAM	60	66	90	109
6.7	BANTAM	70	74	100	120
6.7	BANTAM	80	81	108	130
10.6	MAGPIE	50	33	40	0
10.6	MAGPIE	60	47	52	0
10.6	MAGPIE	70	58	62	0
10.6	MAGPIE	80	67	70	0
21.0	SQUIRREL	50	104	143	179
21.0	SQUIRREL	60	122	165	200
21.0	SQUIRREL	70	138	183	221
21.0	SQUIRREL	80	150	198	238
25.3	GOPHER	50	122	167	206
25.3	GOPHER	60	142	191	233
25.3	GOPHER	70	159	211	255
25.3	GOPHER	80	172	228	275
42.8	FOX	50	148	203	255
42.8	FOX	60	173	234	287
42.8	FOX	70	196	258	314
42.8	FOX	80	213	279	340
40.5	GROUSE	50	163	225	274
40.5	GROUSE	60	191	257	309
40.5	GROUSE	70	213	283	340
40.5	GROUSE	80	232	306	367
52.9	RABBIT	50	186	258	321
52.9	RABBIT	60	218	294	362
52.9	RABBIT	70	243	324	397
52.9	RABBIT	80	264	351	428
63.1	MINK	50	206	285	369
63.1	MINK	60	241	325	411
63.1	MINK	70	270	361	450
63.1	MINK	80	294	391	489
73.4	HORSE	50	246	343	421

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Conducting Area mm ²	ACSR	Temp	Rate A	Rate B	Rate C (15min)
73.4	HORSE	60	290	389	474
73.4	HORSE	70	322	428	520
73.4	HORSE	80	351	462	561
78.8	RACCOON	50	237	330	425
78.8	RACCOON	60	279	377	476
78.8	RACCOON	70	311	416	521
78.8	RACCOON	80	339	451	561
105.0	HARE	50	280	392	534
105.0	HARE	60	335	448	597
105.0	HARE	70	376	496	647
105.0	HARE	80	410	538	697
105.0	DOG	50	282	394	489
105.0	DOG	60	333	450	555
105.0	DOG	70	370	497	612
105.0	DOG	80	404	539	663
116.8	ODIN AC	50	329	458	572
116.8	ODIN AC	60	390	520	643
116.8	ODIN AC	70	433	571	707
116.8	ODIN AC	80	470	615	762
116.8	ODIN DC	50	332	474	603
116.8	ODIN DC	60	397	543	684
116.8	ODIN DC	70	445	601	755
116.8	ODIN DC	80	486	650	813
131.2	TIGER	50	322	466	697
131.2	TIGER	60	393	535	775
131.2	TIGER	70	444	593	845
131.2	TIGER	80	485	643	903
158.1	WOLF	50	363	528	821
158.1	WOLF	60	444	605	918
158.1	WOLF	70	498	671	995
158.1	WOLF	80	547	727	1065
183.4	LYNX	50	401	584	945
183.4	LYNX	60	487	668	1057
183.4	LYNX	70	551	742	1142
183.4	LYNX	80	603	803	1220
200.9	CHICADEE	50	419	602	877

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Conducting Area mm ²	ACSR	Temp	Rate A	Rate B	Rate C (15min)
200.9	CHICADEE	60	496	691	976
200.9	CHICADEE	70	559	761	1070
200.9	CHICADEE	80	608	823	1135
212.1	PANTHER	50	441	642	1095
212.1	PANTHER	60	536	737	1221
212.1	PANTHER	70	606	818	1319
212.1	PANTHER	80	662	883	1414
242.3	PELICAN	50	475	698	1072
242.3	PELICAN	60	572	794	1204
242.3	PELICAN	70	646	874	1329
242.3	PELICAN	80	705	942	1426
264.4	BEAR	50	521	767	1314
264.4	BEAR	60	625	873	1474
264.4	BEAR	70	706	962	1626
264.4	BEAR	80	773	1041	1732
315.0	IEC315	50	573	834	1086
315.0	IEC315	60	687	952	1582
315.0	IEC315	70	774	1050	1714
315.0	IEC315	80	844	1134	1834
322.4	KINGBIRD	50	586	831	1453
322.4	KINGBIRD	60	684	949	1669
322.4	KINGBIRD	70	771	1045	1833
322.4	KINGBIRD	80	837	1136	1893
324.3	GOAT	50	618	866	1683
324.3	GOAT	60	726	996	1840
324.3	GOAT	70	813	1102	1983
324.3	GOAT	80	889	1197	2077
374.1	ANTELOPE	50	627	921	1814
374.1	ANTELOPE	60	761	1060	1927
374.1	ANTELOPE	70	857	1172	2106
374.1	ANTELOPE	80	935	1263	2234
402.3	TERN	50	665	963	1509
402.3	TERN	60	792	1110	1678
402.3	TERN	70	894	1231	1817
402.3	TERN	80	970	1324	1953
403.8	ZEBRA	50	710	1022	1643

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Conducting Area mm ²	ACSR	Temp	Rate A	Rate B	Rate C (15min)
403.8	ZEBRA	60	832	1161	1880
403.8	ZEBRA	70	938	1285	2036
403.8	ZEBRA	80	1024	1391	2136
450.0	IEC450	50	726	1053	1652
450.0	IEC450	60	867	1207	1825
450.0	IEC450	70	970	1330	1986
450.0	IEC450	80	1057	1432	2132
483.8	RAIL	50	755	1109	1432
483.8	RAIL	60	902	1273	1627
483.8	RAIL	70	1101	1408	1793
483.8	RAIL	80	1130	1527	1915
500.0	IEC500	50	781	1133	1824
500.0	IEC500	60	933	1300	2005
500.0	IEC500	70	1043	1434	2181
500.0	IEC500	80	1135	1540	2349
560.0	IEC560	50	844	1230	2036
560.0	IEC560	60	1008	1411	2226
560.0	IEC560	70	1128	1556	2423
560.0	IEC560	80	1226	1673	2608
565.4	ZAMBEZI (DC)	50	852	1234	2044
565.4	ZAMBEZI (DC)	60	1016	1417	2235
565.4	ZAMBEZI (DC)	70	1143	1567	2396
565.4	ZAMBEZI (DC)	80	1250	1688	2564
565.4	ZAMBEZI (AC)	50	841	1220	2023
565.4	ZAMBEZI (AC)	60	1000	1407	2220
565.4	ZAMBEZI (AC)	70	1124	1556	2396
565.4	ZAMBEZI (AC)	80	1229	1691	2352
565.5	BUNTING	50	881	1324	2183
565.5	BUNTING	60	1061	1501	2453
565.5	BUNTING	70	1180	1643	2523
565.5	BUNTING	80	1286	1776	2666
630.0	IEC630	50	909	1343	2212
630.0	IEC630	60	1087	1544	2445
630.0	IEC630	70	1216	1704	2653
630.0	IEC630	80	1325	1838	2849
662.0	DINOSAUR	50	938	1380	2530

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Conducting Area mm ²	ACSR	Temp	Rate A	Rate B	Rate C (15min)
662.0	DINOSAUR	60	1120	1585	2796
662.0	DINOSAUR	70	1267	1763	3009
662.0	DINOSAUR	80	1379	1906	3205
686.5	BERSFORT	50	965	1420	2618
686.5	BERSFORT	60	1153	1630	2899
686.5	BERSFORT	70	1304	1814	3091
686.5	BERSFORT	80	1417	1957	3266
800.0	800-IEC-72/7	50	1089	1595	2092
800.0	800-IEC-72/7	60	1280	1838	2371
800.0	800-IEC-72/7	70	1435	2021	2611
800.0	800-IEC-72/7	80	1555	2177	2820

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Annex D – Copper Conductor Ampere RatingsRho Cu (hard drawn copper) = 0.00381 ohm.mm²/m, alpha = 0.0177746 per °C

Conducting Area mm ²	Copper	Temp	Rate A	Rate B	Rate C (15min)
14.4	C7/0.064	50	102	142	173
	C7/0.064	60	119	162	196
	C7/0.064	70	133	180	216
	C7/0.064	80	145	194	233
38.1	C7/0.104 A	50	206	284	359
	C7/0.104 A	60	244	325	401
	C7/0.104 A	70	273	361	440
	C7/0.104 A	80	296	392	473
38.1	C7/0.104	50	187	260	317
	C7/0.104	60	220	298	359
	C7/0.104	70	245	329	396
	C7/0.104	80	267	357	428
65.1	C7/0.136	50	262	366	448
	C7/0.136	60	308	418	507
	C7/0.136	70	345	463	559
	C7/0.136	80	376	501	604
81.3	C7/0.152 A	50	330	462	612
	C7/0.152 A	60	395	527	685
	C7/0.152 A	70	443	582	746
	C7/0.152 A	80	481	633	802
81.3	C7/0.152	50	300	421	520
	C7/0.152	60	354	483	589
	C7/0.152	70	397	535	648
	C7/0.152	80	434	578	698
97.0	C7/0.166	50	335	473	585
	C7/0.166	60	397	541	663
	C7/0.166	70	444	599	729
	C7/0.166	80	486	649	787
114.0	C7/0.180	50	372	525	654
	C7/0.180	60	441	603	741
	C7/0.180	70	493	666	816
	C7/0.180	80	539	721	881
131.1	C7/0.193	50	406	577	721

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Conducting Area mm ²	Copper	Temp	Rate A	Rate B	Rate C (15min)
	C7/0.193	60	484	660	816
	C7/0.193	70	540	731	900
	C7/0.193	80	591	791	973
39.1	C19/0.064	50	191	266	325
	C19/0.064	60	225	305	367
	C19/0.064	70	251	336	406
	C19/0.064	80	273	365	438
65.8	C19/0.083	50	263	368	452
	C19/0.083	60	310	422	511
	C19/0.083	70	347	466	563
	C19/0.083	80	379	506	609
103.3	C19/0.104	50	348	492	611
	C19/0.104	60	414	564	692
	C19/0.104	70	462	624	762
	C19/0.104	80	506	676	823
119.8	C19/0.112	50	382	543	676
	C19/0.112	60	456	621	766
	C19/0.112	70	508	688	844
	C19/0.112	80	556	744	913
141.6	C19/0.121	50	423	603	875
	C19/0.121	60	505	691	971
	C19/0.121	70	566	766	1057
	C19/0.121	80	621	829	1129
163.9	C19 0.131	50	469	667	842
	C19 0.131	60	558	764	956
	C19 0.131	70	624	846	1055
	C19 0.131	80	683	916	1141
198.1	C19 0.144	50	506	676	823
	C19 0.144	60	631	867	1093
	C19 0.144	70	706	958	1206
	C19 0.144	80	773	1038	1305
344.0	C37 0.136	50	764	1105	1421
	C37 0.136	60	905	1267	1620
	C37 0.136	70	1018	1403	1787
	C37 0.136	80	1113	1516	1933

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Annex E – Steel Conductor Ampere RatingsRho steel = 0.138 ohm.mm²/m, alpha = 0.0045 per °C

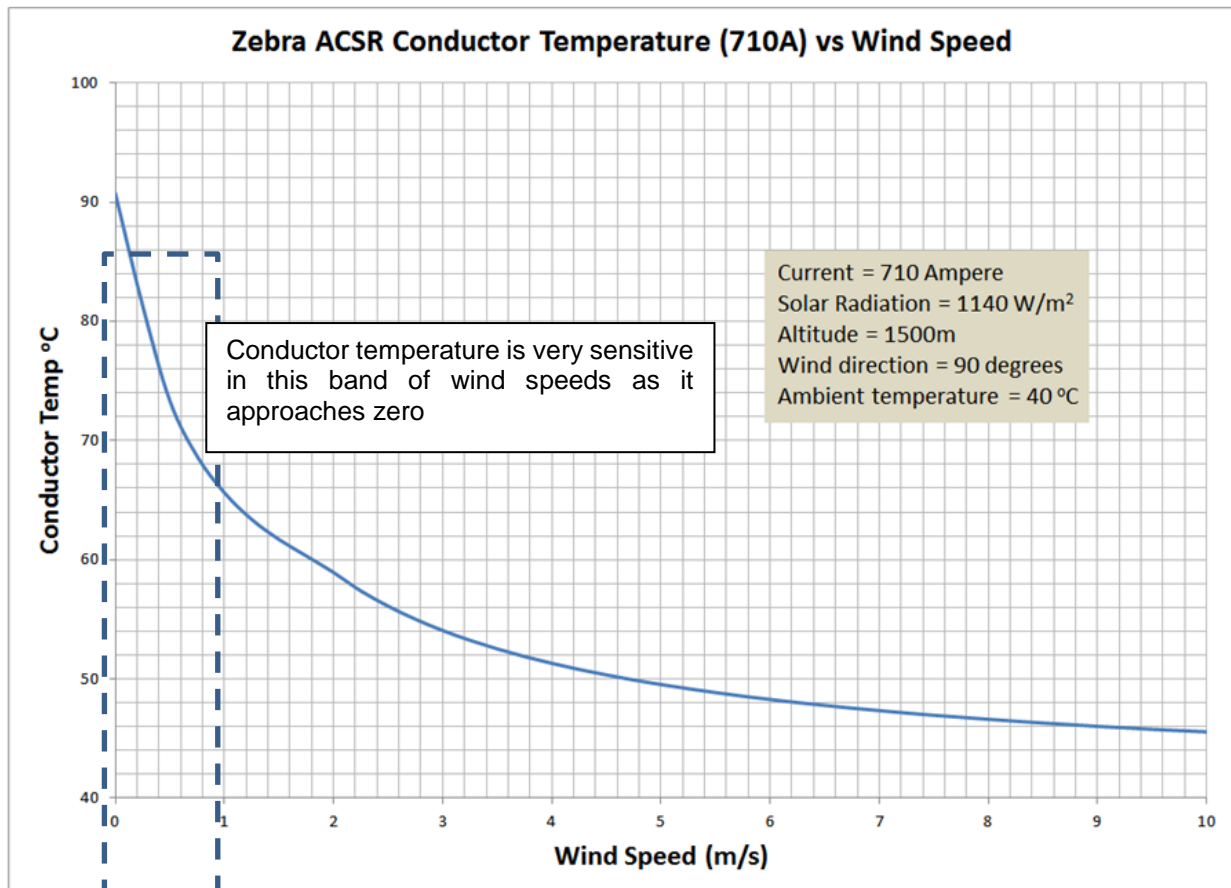
Conducting Area mm ²	Steel	Temp	Rate A	Rate B	Rate C 15min
40.1	7/2.7	50	68	95	120
	7/2.7	60	80	109	134
	7/2.7	70	90	120	146
	7/2.7	80	98	130	158
61.7	7/3.35	50	89	124	163
	7/3.35	60	106	142	180
	7/3.35	70	118	157	197
	7/3.35	80	129	170	211
67.7	7/3.51	50	94	132	175
	7/3.51	60	112	151	193
	7/3.51	70	125	167	210
	7/3.51	80	137	181	226
49.5	19/2.7	50	112	158	226
	19/2.7	60	135	182	251
	19/2.7	70	151	202	273
	19/2.7	80	165	220	290

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Annex F – Ultrasonic vs Cup Anemometer performance

The type of wind speed sensors used in general by weather stations in South Africa is accurate from approximately 1 m/s up to 40 m/s. Many cup anemometers have a lower sensitivity threshold of 0.4m/s, and hence, most data sources report a lot of zero wind speeds which are not truly zero.. When the wind speed drops below 0.4 m/s, the anemometer stops and reads out zero wind speed, and most of these meters will have to experience in excess of 0.4 m/s before the friction in their bearings will be overcome to get it spinning.

Unfortunately, for conductor ampacity calculation purposes, the high number of zero values produced by cup anemometers will adversely affect the ratings due to the fact that convective cooling is severely reduced by this.



Hence, a method was developed to correct the irregular number of zero wind speed values as best as possible.

Two types of wind speed sensors were used side-by-side by Eskom at Zeus substation, in order to determine their respective sensitivities especially in the lower wind speed range between zero and 1 metres per second.

The RM Young 05305 cup anemometer that is used widely in South Africa was compared to the RM Young 81000 Ultrasonic Anemometer. The ultrasonic wind speed meter can measure wind speeds as low as 0.1 m/s and up to 30 m/s within $\pm 1\%$ accuracy.

These two sensors were in operation for more than 1 year a few metres from each other (2003-2004) at the same height on top of a transmission structure, and produced readings every 15 minutes.

05305 Anemometer by RM Young

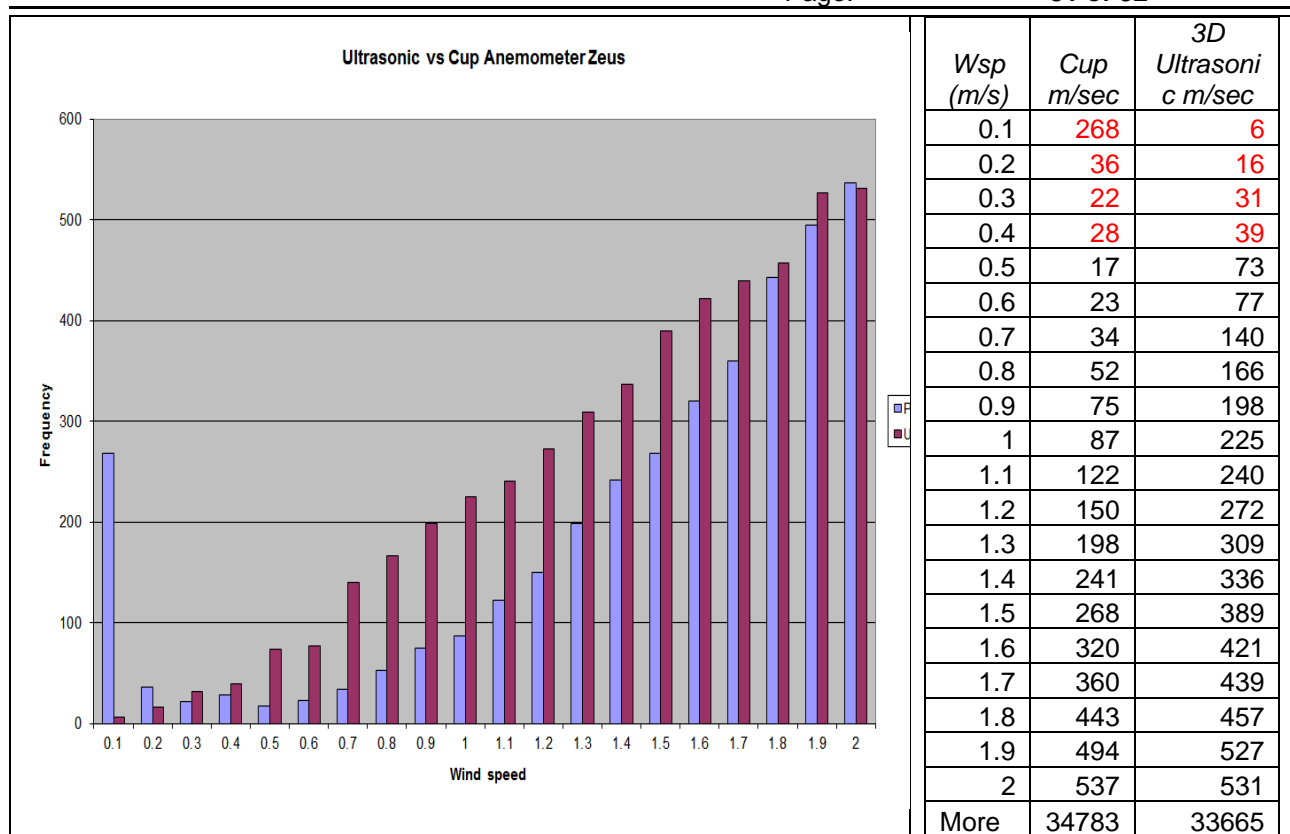


RM Young 81000 Ultrasonic Anemometer



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Comparison of wind speeds below 2m/s measured side by side at Zeus 2004 (Cup vs Ultrasonic sensors)

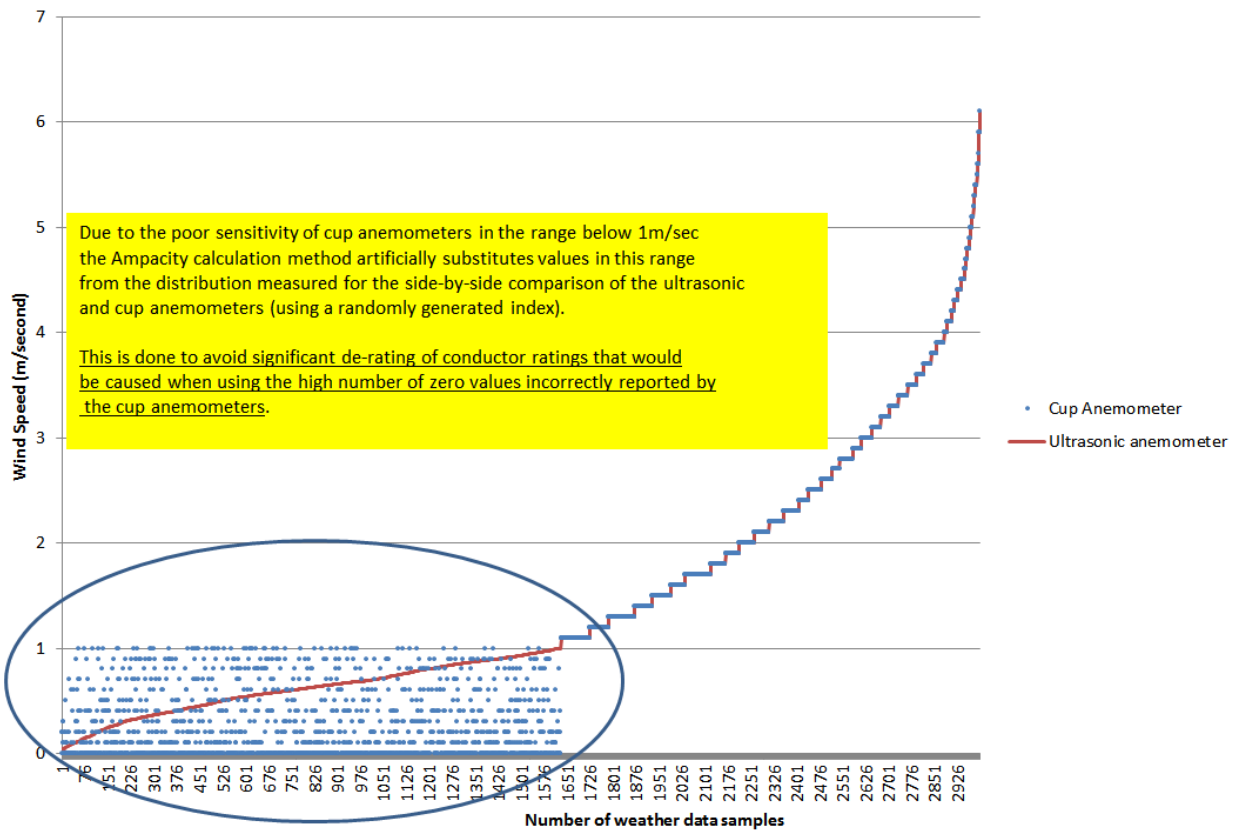
The propeller anemometer produced almost four times as many readings from 0.4m/s and below as compared to the ultrasonic anemometer, which is due to its bearing friction and method of operation.

In order to solve the problem of adversely affected conductor thermal ratings when using data from cup anemometers, a transfer function was derived from the two responses of the two types of meters.

This transfer function can be used to artificially substitute all cup anemometer wind speed readings below 1 metres per second into an estimated set of values determined by using a random index generator, as demonstrated in the example that follows:

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Ultrasonic vs Cup Anemometer Wind Speed Steelpoort 2016-2019



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