SOUTH AFRICAN NATIONAL STANDARD

Electricity distribution — Guidelines for the provision of electricity distribution networks in residential areas

Part 1: Planning and design of distribution networks

This national standard is the identical implementation of NRS 034-1:2007 and is adopted in terms of a Memorandum of Agreement between the Electricity Suppliers Liaison Committee and Standards South Africa.
National foreword

This South African standard was prepared by a working group of the Electricity Suppliers Liaison Committee and adopted by National Committee StanSA SC 67E, *Electricity distribution systems and components – Electricity distribution*, in accordance with procedures of Standards South Africa, in compliance with annex 3 of the WTO/TBT agreement.

The adoption has been done in terms of a Memorandum of Agreement between the Electricity Suppliers Liaison Committee and Standards South Africa.

This part of SANS 507 was published in xxx 2007.
ELECTRICITY DISTRIBUTION —
GUIDELINES FOR THE PROVISION OF
ELECTRICITY DISTRIBUTION NETWORKS
IN RESIDENTIAL AREAS

Part 1: Planning and design of
distribution networks
This rationalized user specification is issued by the Technology Standardization Department (TSD), Eskom, on behalf of the User Group given in the foreword.

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Foreword

This part of NRS 034 was prepared by a working group which, at the time of publication, comprised the following members:

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This document supersedes NRS 034-1:2001 (edition 3.3).

NRS 034 serves as the basis for electricity distribution services that are provided in accordance with the Guidelines for human settlement planning and design (commonly referred to as the Red book) compiled by the CSIR Building and Construction Technology Department and issued under the auspices of the National Housing Board.

NRS 034 consists of the following parts and sections, under the general title Electricity distribution – Guidelines for the provision of electricity distribution networks in residential areas:

Part 0: Definitions.

Part 1: Planning and design of distribution networks.

Part 2: Preferred methods and materials:

Section 1: Substations. (In course of preparation.)
Section 2: Underground cables. (Under consideration.)
Section 3: Prepared methods and materials for the installation of overhead power lines.
Section 4: Area lighting. (In course of preparation.)
Section 5: Low-voltage services. (In course of preparation.)

Part 3: Overhead distribution in very low, low and moderate consumption areas including rural areas and informal settlements.

Part 4: Alternative distribution for rural areas. (Under consideration.)

Part 5: Contract specification. (In course of preparation.)

A reference is made in 4.1.1(a)(1) to "statutory requirements" and in 4.4.1.1 (NOTE 1) to "applicable regulations". In South Africa, this is the Electricity Act, 1987 (Act No. 41 of 1987) (as amended from time to time) and the regulations promulgated in terms of the Act.

A reference is made in 4.8.2 to "Regulation 13 of the Electrical Machinery Regulations" and in clause 6 to "legislation" and to "national or local regulations". In South Africa, this is the Occupational Health and Safety Act, 1993 (Act No. 85 of 1993) (as amended from time to time) and the Electrical Machinery Regulations promulgated in terms of the Act.

Annexes A, B, C and D are for information only.
Introduction

Residential distribution planning and design essentially consist of the placement and sizing of electrical equipment to comply with predicted consumer loads. For low-voltage feeders, voltage drop is the predominant constraint in sizing. Owing to the stochastic (random variation with respect to time) nature of domestic loads, a statistical description of the loads is required. If the load consists of a large number of consumers \( n \), then the total load may be regarded as \( n \) times the mean value of after diversity maximum demand (ADMD). This is due to the phenomenon known as central tendency. However, as the number of consumers forming the load decreases \( n' \), so the uncertainty of the size of a combined load increases and allowance should be made for the probability that the load will exceed \( n' \) times the mean value.

Historically, a factor derived from the number of consumers (coincidence factor) was used to account for this so-called “lack of diversity”. Traditionally, the voltage drop calculation was based on a balanced three-phase system and a further factor was used to compensate for the unbalance of phases. These older formulas ignored the voltage drop in the neutral, particularly when the neutral conductor resistance differed from that of the phase conductors.

Data loggers developed initially at the University of Stellenbosch during 1987 and subsequently by Eskom have been used to gather statistical load data. Analyses of these data over years have led to the following observations:

– domestic loads can be modelled as currents;

– loads lie within a finite positive range of values – between zero and the circuit-breaker size;

– when a frequency of occurrence histogram of the load currents is plotted, it is best modelled by a Beta probability density function (pdf); and

– the load pdf can be either skewed to the left or right (shape).

The statistical parameters of the Beta pdf are \( a \), \( b \) and scaling value \( c \). In contrast, a Gaussian pdf has parameters: mean (\( \mu \)) and standard deviation (\( \sigma \)). The mean value of the load can be regarded as the ADMD (in amperes or in kilovolt amperes at nominal 230 V). The Gaussian pdf has no limits and cannot be skewed. It is therefore not a good representation of the domestic load. It is therefore necessary to have three parameters to adequately describe load: location, dispersion and shape. This is achieved by the Beta pdf.

For those who are only familiar with the older ADMD/diversity factor combination, the new load model can be derived in the following way:

– use the circuit-breaker size as the scaling value, \( c \);

– set the estimated ADMD in amperes (i.e. the mean of target community) equal to \( ac/(a + b) \);

– for the given mean and \( c \) values, consider \( a \) as an indicator of shape (this is not strictly true as \( a \), \( b \) and \( c \) together give shape). The value of \( a \) needs to be obtained for the target community from the NRS Load Survey project; and

– calculate the remaining load parameter, \( b = a (c/ADMD - 1) \).

Alternatively, all three load parameters, \( a \), \( b \) and \( c \) can be obtained from the NRS Load Research Project or may be estimated from table 2 of this part of NRS 034. Other load modelling issues are dealt with in 4.3.
Introduction (concluded)

Beta distributed load currents can be transformed into another beta distribution of voltage drops by using the Herman-Beta method. The Herman-Beta method is the most comprehensive and accurate method available for calculating voltage drops in low-voltage residential feeders. The Voltage Drop Working Group of the NRS 034-1 committee has adopted the Herman-Beta method with regard to these design guidelines. A risk value has to be chosen by the designer since it is a probabilistic (rather than deterministic) method. A common value is 10 %. The Herman-Beta method is suitable for use in spreadsheet applications. Worksheets are available from the NRS Project Management Agency for both three-phase and biphase (or dual-phase) systems.

Keywords

electricity distribution, guidelines for planning and design, residential areas.
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ELECTRICITY DISTRIBUTION — GUIDELINES FOR THE PROVISION OF ELECTRICITY DISTRIBUTION NETWORKS IN RESIDENTIAL AREAS

Part 1: Planning and design of distribution networks

1 Scope

This part of NRS 034 covers the planning and design of economical residential electricity distribution networks that are capable of compliance with probable demands with safety and reliability, whilst maintaining the voltage within the prescribed limits. It is a general guide to good technical practice for economical overhead and underground systems.

NOTE Electricity distribution networks are required to comply with the performance requirements of NRS 048-2 but there is currently no definitive link between this part of NRS 034 and NRS 048-2.

2 Normative references

The following documents contain provisions which, through reference in this text, constitute provisions of this part of NRS 034. All documents are subject to revision and, since any reference to a document is deemed to be a reference to the latest edition of that document, parties to agreements based on this specification are encouraged to take steps to ensure the use of the most recent editions of the documents listed below. Information on currently valid national and international standards can be obtained from Standards South Africa.

2.1 Standards

IEC 60909-0, Short-circuit currents in three-phase a.c. systems – Part 1: Calculation of currents.

SANS 97 (SABS 97), Electric cables – Impregnated paper-insulated metal-sheathed cables for rated voltages 3,3/3,3 kV to 19/33 kV (excluding pressure assisted cables).

SANS 182-1 (SABS 182-1), Conductors for overhead electrical transmission lines – Part 1: Copper wires and stranded copper conductors.


SANS 182-3, Conductors for overhead electrical transmission lines – Part 3: Aluminium conductors, steel reinforced.

SANS 182-5 (SABS 182-5), Conductors for overhead electrical transmission lines – Part 5: Zinc-coated steel wires for conductors and stays.

SANS 780, Distribution transformers.

SANS 1339, Electric cables – Cross-linked polyethylene (XLPE) insulated cables for rated voltages 3,8/6,6 kV to 19/33 kV.

SANS 1418-1 (SABS 1418-1), Aerial bundled conductor systems – Part 1: Cores.

SANS 1524-1, Electricity payment systems – Part 1: Prepayment meters.

SANS 10098-1 (SABS 098-1), Public lighting – Part 1: The lighting of public thoroughfares.

SANS 10098-2, Public lighting – Part 2: The lighting of certain specific areas of streets and highways.


SANS 10198-3, The selection, handling and installation of electric power cables of rating not exceeding 33 kV – Part 3: Earthing systems – General provisions.

SANS 10198-5, The selection, handling and installation of electric power cables of rating not exceeding 33 kV – Part 5: Determination of thermal and electrical resistivity of soil.

SANS 10198-12 (SABS 0198-12), The selection, handling and installation of electric power cables of rating not exceeding 33 kV – Part 12: Installation of earthing system.

SANS 10199, The design and installation of earth electrodes.

SANS 10280 (SABS 0280), Overhead power lines for conditions prevailing in South Africa.

SANS 10292 (SABS 0292), Earthing of low-voltage (LV) distribution systems.

SANS 61089/IEC 61089 (SABS IEC 61089), Round wire concentric lay overhead electrical stranded conductors.

SANS 62051/IEC 62051, Electricity metering – Glossary of terms.

SANS 62052-11/IEC 62052-11, Electricity metering equipment (a.c.) – General requirements, tests and test conditions – Part 11: Metering equipment.

SANS 62053-21/IEC 62053-21, Electricity metering equipment (a.c.) – Particular requirements – Part 21: Static meters for active energy (classes 1 and 2).

VDE 0636-301, Low-voltage fuses: D-system – Protection of cables and cords up to 100 A and 500 V and/or up to 63 A 660 V a.c. or 600 V d.c.

2.2 Other publications


NRS 013, Medium-voltage cables.

NRS 033, Electricity distribution – Guidelines for the application design, planning and construction of medium voltage overhead power lines up to and including 22 kV, using wooden pole structures and bare conductors.

NRS 034-0, Electricity distribution – Guidelines for the provision of electrical distribution networks in residential areas – Part 0: Definitions.

NRS 034-3, Electricity distribution – Guidelines for the provision of electrical distribution networks in residential areas – Part 3: Overhead distribution in very low, low and moderate consumption areas, including rural areas and informal settlements.
3 Terms, definitions and abbreviations

For the purposes of this part of NRS 034, the definitions and abbreviations given in NRS 034-0 and the following apply:

3.1 Terms and definitions

**beta distribution**
\( \beta \)
statistical distribution function such as can be used to describe the electrical load of a group of consumers at any given time

**dual-phase system**
**biphase system**
distribution system, with two live conductors and a neutral, fed from a centre-tapped single-phase transformer winding

**node**
point of common connection of consumer service conductors to a feeder, or a branch point in a feeder

3.2 Abbreviations

<table>
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<th>Definition</th>
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<tr>
<td>ACE</td>
<td>Association of Consulting Engineers</td>
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<tr>
<td>ADMD</td>
<td>after diversity maximum demand</td>
</tr>
<tr>
<td>AIEE</td>
<td>American Institute of Electrical Engineers</td>
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<tr>
<td>AMPS</td>
<td>All Media and Product Survey</td>
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<tr>
<td>ASEA</td>
<td>General Swedish Electrical Limited Company</td>
</tr>
<tr>
<td>CIRED</td>
<td>Congrés International des Réseau Electriques de Distribution</td>
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<tr>
<td>CPI</td>
<td>consumer price index</td>
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<tr>
<td>CSP</td>
<td>completely self-protecting</td>
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<tr>
<td>EPCC</td>
<td>Electric Power Coordinating Committee</td>
</tr>
<tr>
<td>GIS</td>
<td>Geographic Information System</td>
</tr>
<tr>
<td>HRC</td>
<td>high rupturing capacity</td>
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<tr>
<td>IDMTL</td>
<td>inverse definite minimum time lag</td>
</tr>
<tr>
<td>IEEE</td>
<td>Institute of Electrical and Electronic Engineers</td>
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<tr>
<td>IEE</td>
<td>Institution of Electrical Engineers</td>
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<tr>
<td>LF</td>
<td>load factor</td>
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<tr>
<td>LLF</td>
<td>loss load factor</td>
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<tr>
<td>LSM</td>
<td>living standards measure</td>
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<tr>
<td>MCCB</td>
<td>moulded-case circuit-breaker</td>
</tr>
<tr>
<td>NPV</td>
<td>net present value</td>
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<tr>
<td>PU</td>
<td>per unit</td>
</tr>
<tr>
<td>PV</td>
<td>present value</td>
</tr>
<tr>
<td>SAIIEE</td>
<td>South African Institute of Electrical Engineers</td>
</tr>
<tr>
<td>SDP</td>
<td>service distribution point</td>
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</table>
4 Planning and design

4.1 Factors that influence network design

4.1.1 The factors that influence network design and need to be considered fall into the following three categories:

a) fixed parameters within which the electrical designer might have to work, which include

1) statutory requirements (see foreword),
2) existing services (for example oil pipelines),
3) existing residential area layout,
4) number of dwellings per hectare,
5) nature of the terrain,
6) geographic location (for example, coastal or inland), and
7) capital limitations;

b) factors over which the designer has limited or no control, which include

1) consumer loads (see 4.3), and
2) diversity;

c) factors over which the designer should exercise control, which include

1) initial capital costs and life cycle costs,
2) new residential area layout,
3) number and positioning of metering points,
4) cable and conductor sizes and types of cable and conductor,
5) number, sizes, locations and types of substation,
6) voltage drop and unbalance, within limits of design load, and
7) quality of supply.

NOTE No design should be considered in isolation. The planner should take into account the relationship between the area to be supplied and adjacent supply areas, proposed future developments and environmental considerations.

When applying the guidelines to individual schemes, it is necessary to take into account all local conditions and total life cycle cost (for example, capital outlay and the upgrading of operational and maintenance requirements).

4.1.2 Climatic conditions should also be taken into account since they will influence the design of an electricity distribution network. For information on how to take account of climatic conditions in the design of overhead lines, see SANS 10280.

Some examples of the effects of climatic conditions on overhead lines are:
4.2 Planning procedure

4.2.1 Co-ordination of services

4.2.1.1 The following engineering services should be considered when a residential area is being planned:

a) the layout of stands for housing, parks, schools, roads and sidewalks;

b) gravity-dependent services such as stormwater drainage and sewerage;

c) water reticulation and fire hydrants;

d) electrical distribution and street lighting systems;

e) overhead and underground telecommunication systems; and

f) gas distribution systems.

NOTE An integrated approach should be followed to minimize the overall cost of the services that are affected by the residential area layout.

4.2.1.2 In South Africa, the following organizations should be consulted, since their services might be affected by the provision of electricity distribution systems:

a) all telecommunication authorities including Telkom and any other licensed provider(s) of telecommunication services;

b) the Department of Transport;

c) Transnet, with regard to railways;

d) Petronet, with regard to oil pipelines;

e) private land owners and public supply authorities (including regional water boards), with regard to water pipes;

f) all supply authorities including Eskom, municipalities and any other similar organizations that are licensed to distribute electrical power, with regard to power line and cable servitudes and way-leaves;

g) SASOL Gas Limited (formerly the Gas Distribution Corporation (GASCOR) and private gas companies; and

h) local and regional authorities with regard to municipal services.
4.2.2 External supply

Ensure that the external supply is adequate to cater for the estimated system peak load, which is equal to the estimated maximum demand of the residential load plus other loads that contribute to the system peak load, for example, street lighting, shopping centres and sports arenas.

Calculate the estimated maximum demand of the residential load in kilovolt amperes (kVA), by using the following formula (see 4.3.4):

\[
L = 0.23 \times N \times \frac{c}{a+b} \left[ a + 1,28 \sqrt{\frac{a \times b}{N(a+b+1)}} \right]
\]

where

- \(L\) is the maximum load, in kilovolt amperes;
- \(N\) is the total number of consumers;
- \(a, b\) and \(c\) are the load current model parameters.

When transformers are being sized, coincidental bulk loads such as those due to pumps, schools, shops, etc., should be added.

The location of the point of connection of the external supply should always be agreed upon with the external supply authority as soon as planning starts (see annex A).

4.2.3 Internal network

4.2.3.1 General

4.2.3.1.1 Examine the layout of the stands and decide on the type of technology to be used by referring to 4.2.3.2. The dual-phase option is often a good choice when the most convenient number of consumer connections at each node is a multiple of two.

4.2.3.1.2 The steps to be followed in the design of the internal network are given in 4.2.3.1.3 to 4.2.3.1.16.

4.2.3.1.3 Determine the optimum number of service connections per service distribution point (SDP) that will depend on variables such as

a) the installation cost of an SDP,

b) the cost of the service connection from the SDP to each consumer, and

c) the additional voltage drop for long service connections.

4.2.3.1.4 Remember that the supply from the substations to SDPs is normally radial.

4.2.3.1.5 Link the SDPs to establish routes for distributors. Optimize the route lengths with regard to substation costs and cable/conductor costs. The relationship is typically as shown in figure 1.

4.2.3.1.6 Determine the ideal positions of substations to supply the distributors. The overall cost of the scheme is affected by the position of each substation. Position substations near load centres. In cases where shopping centres, schools, petrol stations and other large power users are to be supplied, so position the substation which supplies these loads that any spare transformer capacity is utilized effectively for adjacent residential consumers. Optimize the position of each substation by taking into consideration servitude requirements and practical sites.
4.2.3.1.7 Calculate the number and size of the substations needed to supply the total estimated load while taking into account the preferred transformer sizes (see preferred transformer sizes in table 1).

![Diagram](image)

**Table 1 — Preferred transformer ratings (kVA)**

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<td><strong>Pole-mounted MV/LV transformers</strong></td>
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<tr>
<td>Three-phase</td>
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<td>Dual-phase (bi-phase)</td>
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<td>Single-phase</td>
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<td>200</td>
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<tr>
<td><strong>Minisubstations and ground-mounted transformers</strong></td>
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4.2.3.1.8 Consider both the optimum radius of LV distribution and the cost of looping the medium-voltage (MV) distribution to the substation (see 4.2.3.1.5).

4.2.3.1.9 Determine the LV distributor sizes in relation to the load and voltage drop (see 4.4).

**NOTE** Tapering of conductor sizes will often give the lowest first-cost solution, but this advantage needs to be evaluated against the potential cost of future upgrading.

4.2.3.1.10 Design the backbone layout with due regard to the sharing of structures/trenches for MV, LV and street lighting systems. Where feasible, the sharing of poles with overhead telephone services should be considered.

4.2.3.1.11 Determine circuit-breaker, isolator and other protection and control requirements.
4.2.3.12 Design the street-lighting layout with reference to SANS 10098-1, SANS 10098-2 and the AMEU/ILESA/SANCI Guide for the installation and maintenance of street lighting.

4.2.3.13 Consider the means of future network upgrading for growth in load and check on the feasibility of the design to make provision for upgrading.

4.2.3.14 Determine the cost of the complete design, and the average cost for each residential property. Compare these costs with known average costs for a similarly designed supply area. Re-check the design for possible cost savings.

4.2.3.15 Estimate the cost of losses over the economic life of the network and capitalize those losses. Compare the costs, using increased sizes of cables or conductors (to minimize losses), and identify the most cost-effective choice.

4.2.3.16 Where alternative materials are considered, include their impact on the lifetime maintenance costs when deciding which materials to use.

NOTE The initial capital available might preclude the most cost-effective long-term design.

4.2.3.2 LV distribution topology

The following three types of LV distribution systems are available:

a) three-phase, four-wire;

b) single-phase; and

c) dual phase (biphase).

The arrangement of the conductors and transformers is shown in figure 2.

![Figure 2 — LV distribution topologies](image_url)

4.2.3.3 Phase assignment of consumers

Voltage drop in a feeder is affected by the way consumers are connected to the supply. Generally, with aerial bundled conductor (ABC) and overhead bare conductor feeders, up to four consumers can be connected to a phase conductor using one clamp. Depending on the system topology, the physical arrangement of the stands and the position of the poles or SDPs, consumers can be connected to the phase conductors in a variety of patterns.

The following convention identifies the patterns:

- cyc mmm; cos mmm; bal mmm
where

cyclic refers to assignment: red, white, blue, red, white, blue ...

cosine refers to assignment: red, white, blue, blue, white, red ...

balanced refers to the connection of equal numbers of consumers to each phase at every node, and

m is the number of consumers connected to the same point.

Examples:

a) Cos 400 refers to a three-phase cosine arrangement with four consumers connected to one phase at a node.

b) Cyc 211 refers to a three-phase cyclic arrangement with two consumers connected to one phase and one each to the other two phases at a node.

c) Bal 22 refers to a dual-phase arrangement where four consumers are connected at a node, two consumers per phase.

4.3 Load modelling

4.3.1 Uncertainty in load modelling

The largest source of uncertainty in LV distribution design is in the modelling of the design loads. A good way to deal with uncertainty is to use probabilistic rather than deterministic design methods. Research has resulted in probabilistic design algorithms appropriate to Southern African conditions. This work is reflected in 4.3.2 to 4.3.6.

4.3.2 Electrical description of loads

Analysis of extensive load data collected in South Africa validates the assumption that domestic electrical loads can be modelled as constant current sinks. This model also obviates the need for iterative procedures in voltage drop calculations. Loads will therefore be referred to in terms of amperes rather than kilovolt amperes or kilowatts. The heaviest loads generally have a large resistive heating component resulting in a load power factor close to unity. It is therefore appropriate to consider loads as currents at unity power factor for the purpose of voltage drop calculation.

A more accurate description of the load necessitates a statistical approach. Based on load research, statistical probability functions have been derived for various loads. These functions are derived from histograms of the load currents of all the consumers' loads taken at representative periods. The resulting distribution represents the consumer load that causes the greatest voltage drop (worst case) in the system. This worst case could result from an increased demand or severe unbalance or both.

It is necessary to model the connection of the actual loads to the system as accurately as possible and, in this regard, it is particularly advantageous to use the Herman-Beta algorithm for voltage drop calculations. A typical unbalanced connection might be where four consumers are connected to only one phase at each node.

4.3.3 Statistical description of loads

Load currents at maximum demand, or any other instant, are statistically distributed. This distribution of currents can be represented as a histogram of frequency of occurrence (or probability) against current (in amperes). A statistical expression, known as a probability density
function or pdf can be derived from the histogram. A common pdf is the Gaussian or normal pdf shown in figure 3. Such a distribution describes the mean (average value) and also the dispersion (or spread of values, expressed as the standard deviation).

![Figure 3 — Typical Gaussian (normal) load distribution](image1)

While this symmetrical description is suitable for a large number of combined loads (>30), it is generally unsuitable for smaller groups (as in distribution design). In these cases, the pdf of the load currents might be skewed to the right or the left, as shown in figure 4. The skewness depends on a variety of factors such as the presence of hot water cylinders and circuit-breaker size.

![Figure 4 — Typical load distributions](image2)

Two statistical parameters are required to describe a symmetrical distribution such as the Gaussian pdf, but three parameters are needed when skewness is included. A convenient pdf for this purpose is the Beta pdf with parameters: $a$, $b$ and $c$ (see table 2). By varying the relationship between $a$, $b$ and $c$, a family of curves can be derived that will fit most practical load distributions.
The parameter $c$ is the scaling parameter and is often taken as the consumer circuit-breaker size or larger.

The mean value of the Beta pdf is given by:

$$c = \frac{a}{a + b}$$

A Beta pdf may be rescaled to any new value, $c'$, as long as $c'$ is larger than the original mean value (see B.4).

Loads described by the Beta pdf are used in voltage drop calculations by the Herman-Beta method. While the derivation of the Herman-Beta algorithm can be complicated, the resulting calculation steps are linear and may, for example, be incorporated into standard spreadsheet programs (see annex B). The Herman-Beta method is an accurate probabilistic approach for dealing with various load types, network topology and consumer connection arrangements.

4.3.4 Estimating the $a$, $b$ and $c$ parameters of loads

4.3.4.1 General

Where the load data are available, the $a$ and $b$ parameters can be derived for any given values of $c$, using the mean ($\mu$) and the standard deviation ($\sigma$) of the data.

$$a = \frac{\mu(c\mu - \mu^2 - \sigma^2)}{ca^2}$$

$$b = \frac{(c - \mu)(c\mu - \mu^2 - \sigma^2)}{ca^2}$$

4.3.4.2 Characteristics to be considered

Load estimation for urban or rural domestic consumers is very important in the cost of the electrification system. Overestimation ("safe estimate") will result in overcapitalization, while underestimation results in a poor quality of supply which could lead to expensive reinforcement later.

Several demographic factors affect load statistics. These include income, availability of piped water, type of dwelling, size of dwelling, size of household, ambient temperature, distance from main centres and shift work.

System load increases as a result of increased consumption of individual consumers (with time, responding to changes in income, family size, availability of household appliances, and habits of using electricity) and the connection of new consumers to the existing network. The exact load growth depends on the consumers, community and utility operations, and a typical curve of system load growth is depicted in figure 5. A convenient simplification of the load growth forecast is to use load estimates at two time horizons, such as 7 and 15 years ahead.
<table>
<thead>
<tr>
<th>Current type</th>
<th>Load parameters – 7 years(^{1,2})</th>
<th>Load parameters – 15 years(^{1,2})</th>
</tr>
</thead>
<tbody>
<tr>
<td>Consumer class</td>
<td>AMPS(^a) and LSM(^a) class</td>
<td>Income range(^b) (gross R/month)</td>
</tr>
<tr>
<td>Rural settlement</td>
<td>LSM 1 (low end)</td>
<td>0 to 600</td>
</tr>
<tr>
<td>Rural village</td>
<td>LSM 1 and 2</td>
<td>400 to 900</td>
</tr>
<tr>
<td>Informal settlement</td>
<td>LSM 3 and 4</td>
<td>800 to 1 500</td>
</tr>
<tr>
<td>Township area</td>
<td>LSM 5 and 6</td>
<td>1 500 to 3 000</td>
</tr>
<tr>
<td>Urban residential I</td>
<td>LSM 7</td>
<td>3 000 to 5 500</td>
</tr>
<tr>
<td>Urban residential II</td>
<td>LSM 7 and 8</td>
<td>5 500 to 8 500</td>
</tr>
<tr>
<td>Urban township complex</td>
<td>LSM 8</td>
<td>8 500 to 12 000</td>
</tr>
<tr>
<td>Urban multi-storey/estate(^f)</td>
<td>LSM 8 (high end)</td>
<td>12 000 to 24 000</td>
</tr>
</tbody>
</table>

\(^a\) Living standards measure (LSM) as quoted in the All Media and Product Survey (AMPS) conducted annually by the South African Advertising Research Foundation.

\(^b\) Average household income ranges shown for comparative purposes are in 2005 Rands. Any income data collected at a later date should be deflated by the CPI to allow a direct comparison.

\(^c\) If the target community matches the description, but the chosen value of \(c\) is different, new \(a\) and \(b\) values can be calculated for the chosen value of \(c\), using the formula given in B.4.3.

\(^d\) Parameters have been normalized to the climate in the interior of South Africa where the winters are generally cold and with low rainfall. In regions where the winter is cold and wet (e.g. Cape Peninsula), the ADMD is about 12 % higher than that given. In climates similar to that of the Durban coastal region, the ADMD is about 12 % lower than that given.

\(^e\) Except as indicated in \(f\) below, the parameters have been derived from carefully monitored case studies around the country, and reflect best knowledge at the time of publication of actual consumer demand over time. The actual load parameters used depend upon the strategy of the planner with regard to phasing of capital expenditure.

\(^f\) Parameters for this consumer class have been extrapolated from existing data, since no sample load data have yet been collected from such consumers. Loads significantly higher than the ADMD shown in LSM 8 (high end) can be expected in the case of specific high-consumption developments. In such cases, estimated load data should be obtained from the relevant local authority or licensee.

---

\(^1\) Table 2 is administered by the NRS Project Management Agency (PMA) on behalf of the Electricity Supply Industry. The table is updated from time to time, based on the analysis of the latest available load research data without this part of the specification being revised. The current table can be viewed on the NRS website: <www.nrs.eskom.co.za> or obtained from the NRS Projects Manager.

NOTE Contact details for the NRS Projects Manager are:

Telephone +27 11 651 6846; Fax +27 11 651 6827; Postal address: Industry Association Resource Centre, Technology Standardization, Eskom Convention Centre, PO Box 1091, Johannesburg 2000
The design parameters selected for any particular residential area will influence all major sizing parameters and have a significant effect on both the initial capital costs and the system lifetime costs (see table 3).

Table 3 — Characteristics to be considered and their effects on the electrical load

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Effect on design load</th>
</tr>
</thead>
<tbody>
<tr>
<td>Economic class of present and future residents</td>
<td>This will determine the appliances present in a household.</td>
</tr>
<tr>
<td>Social characteristics, e.g. number of persons or households on each stand</td>
<td>The estimated future usage patterns of appliances that contribute significantly to a consumer's load at times of peak demand, e.g. hotplate/stove, space heating, water heating, washing machine, tumble dryer and air conditioner, can increase the ADMD selected.</td>
</tr>
<tr>
<td>Community habits (shift work, etc.)</td>
<td>If a large percentage of a residential area’s population works fixed hours (e.g. shift work at a mine or factory), the parameters of the load model might have to be changed (see 4.3.4.4).</td>
</tr>
<tr>
<td>Load control methods (“ripple control”, load limit switches or circuit-breaker tariffs)</td>
<td>Take cognizance of the influence of “ripple-control” on electric water heaters, where this is to be applied, and reduce the ADMD accordingly.</td>
</tr>
<tr>
<td>Cost of, ease of use of, availability of, and social preference for, alternative energy sources</td>
<td>The estimated continued usage of alternative energy in the future as a substitute for major energy appliances, e.g. the use of coal stoves instead of electric stoves or hotplates, can reduce the ADMD chosen.</td>
</tr>
</tbody>
</table>

4.3.4.3 Consumer load classes

Load research has shown that domestic consumers are broadly divided into two load classes: those who have access to piped water and those who do not. The implication is the probable (if not certain) use of electrical hot water cylinders (HWCs) by those who have access to piped water. Previous consumer load classification neglected to cater for differences within the lower income groups (the groups which account for most of the electrification projects). Current load research is aimed at providing load forecasting algorithms and tools but this is still under development.
4.3.4.4 Selection of design parameters: $a$, $b$, $c$

4.3.4.4.1 Estimate the likely demographic characteristics as set out in 4.3.4.4.2 to 4.3.4.4.8.

4.3.4.4.2 Determine whether the target community will be supplied with piped water.

4.3.4.4.3 Estimate the average monthly income of the community in 2005 Rands. The national consumer price index (CPI) should be used where necessary to derive the 2005 Rand value from later income data.

4.3.4.4.4 Determine the type of dwelling: shack, brick, etc.

4.3.4.4.5 Determine whether climatic conditions need special consideration.

4.3.4.4.6 Determine whether load limiting will be employed. If so, change the beta parameters of the load model accordingly. It is not necessary to change $c$, but $a$ and $b$ will change to reflect the effects of load limiting.

4.3.4.4.7 Decide on the horizon year to be used, depending on the permanence of the infrastructure.

4.3.4.4.8 Having made an estimate, select the closest consumer load class from table 2, taking into account the description of consumer classes in table 4. For the relevant value of $c$, derive the values $a$ and $b$.

4.3.5 Enhancements to the Herman-Beta method

The Herman-Beta calculation method and load models described in annex B have been enhanced as compared to the description of this method in the previously published edition of this part of NRS 034 (NRS 034-1:1999), and are as follows:

- a) different $a$, $b$ and $c$ load parameters can be specified at each load node (different load classes can be mixed in the same study where the class of the load at each individual load node is known);

- b) a new set of $a$, $b$ and $c$ load parameters can be derived for a mixture of two load classes (different load classes can be mixed in the same study where the ratio of each load class is known but the class of the load at each individual load node is unknown); and

- c) fixed loads can be included in the study. Load power factor is ignored (assumed to be unity), but adjustments can be included to account for constant power load voltage sensitivity.

4.3.6 Conductor parameters

4.3.6.1 Cables and conductors should be selected from the types and sizes of cable and conductor recommended in the following standards, as applicable:

- SANS 97: Paper-insulated, metal-sheathed cables;
- SANS 182-1, SANS 182-2, SANS 182-3 and SANS 182-5: Overhead conductors;
- SANS 1339: XLPE-insulated cables;
- SANS 1418-1 and SANS 1418-2: LV aerial bundled conductor systems;
- SANS 61089: Overhead stranded conductors.
4.3.6.2 Where applicable and wherever practicable, cables and conductors should be selected from the preferred types and sizes of cable and conductor specified in the following NRS specifications:

- NRS 013: MV underground cables;
- NRS 033: Conductors for MV overhead lines;
- NRS 034-3: Conductors and ABC for LV overhead lines.

4.3.6.3 The cable data required by the designer are the phase resistance $R_p$ and the neutral resistance $R_n$. Specifically, the resistances at the operating temperature have to be taken into account when the voltage drop is being calculated. For underground conductors, an operating temperature of 30 °C is assumed. For overhead conductors, an operating temperature of 40 °C is assumed in voltage drop calculations, although higher temperatures are used for calculating the minimum ground clearance of the conductors for safety considerations.

4.4 Voltage regulation of LV distributors

4.4.1 Limits of voltage variation

4.4.1.1 Base the LV design on a maximum calculated voltage variation of ± 10 % of the standard voltage at the consumer’s point of supply. This means that the total voltage variation at the end consumer shall not exceed 20 %.

NOTE 1 The standard nominal voltage, as required by the applicable regulations (see foreword), is 230 V.

NOTE 2 NRS 048-2 recommends that, in the case of a distribution system with a nominal system voltage lower than 500 V, the supply voltage does not deviate from the standard voltage by more than 10 %.

NOTE 3 Statistical monitoring of voltage regulation is required by the National Energy Regulator of South Africa (NERSA).

NOTE 4 Designing for a higher voltage variation means lower initial costs, but higher losses.

NOTE 5 See 5.3 for the selection of transformers.

4.4.1.2 As a general guide, the following are typical contributions, expressed as a percentage of the standard nominal voltage to the percentage voltage variation at the most remote consumer:

<table>
<thead>
<tr>
<th>Source</th>
<th>Contribution</th>
</tr>
</thead>
<tbody>
<tr>
<td>MV source</td>
<td>± 1,5 % or a total of 3 % variation (this allows for variations at the MV substation busbars, due to, for example, tap-changer steps and automatic voltage regulator hysteresis);</td>
</tr>
<tr>
<td>MV distributor</td>
<td>3 %;</td>
</tr>
<tr>
<td>Transformer</td>
<td>2 % (unless high-loss transformers, such as completely self-protected (CSP) transformers, are being used);</td>
</tr>
<tr>
<td>LV feeder</td>
<td>8 %;</td>
</tr>
<tr>
<td>Service connection</td>
<td>2 %;</td>
</tr>
<tr>
<td>Total</td>
<td>18 %;</td>
</tr>
<tr>
<td>Consumer load class</td>
<td>Derivation of income</td>
</tr>
<tr>
<td>----------------------</td>
<td>--------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Rural settlement</td>
<td>Mainly from pensions and subsistence farming. Some breadwinners work far away in cities.</td>
</tr>
<tr>
<td>Rural village</td>
<td>From pensions and subsistence farming. Some breadwinners are employed in nearby industrialized areas and commute daily.</td>
</tr>
<tr>
<td>Informal settlement</td>
<td>From work in a nearby town or city – largely from the informal sector</td>
</tr>
<tr>
<td>Township area</td>
<td>From work in cities or towns, pensions, and some informal employment</td>
</tr>
<tr>
<td>Urban residential I</td>
<td>From blue-collar jobs in cities</td>
</tr>
<tr>
<td>Urban residential II</td>
<td>From formal employment in cities, mostly white-collar jobs</td>
</tr>
<tr>
<td>Urban township complex</td>
<td>Mainly from professional jobs in cities, level of employment is high.</td>
</tr>
<tr>
<td>Urban multi-storey/estate</td>
<td>Mainly from professional jobs in cities, level of employment is very high.</td>
</tr>
</tbody>
</table>
4.4.1.3 This allows a small reserve over the maximum permitted fluctuation at the consumer's point of supply, which takes into account that the MV source might not be operated at +10 % of nominal voltage.

Where an LV system is being supplied by a long MV feeder, such as that found on rural overhead lines, the voltage variation on the MV system might be higher, in which case a lower percentage voltage variation will have to be adopted for the LV distributor and service connection.

The practical design parameters should be based on compliance with the minimum standards for voltage regulation as set out in NRS 048-2.

4.4.2 Voltage drop calculation algorithm

The voltage drop in the LV distributor is calculated by means of the Herman-Beta algorithm described in B.2 and B.3. Although the algorithm is based on statistical analysis, it is easy to implement in a spreadsheet. Two worksheets are available (for biphasic and for three-phase systems) based on two popular spreadsheet programs. Outputs from commercial computer packages using the Herman-Beta algorithms should be examined for accuracy by applying the benchmark tests given in B.8. Examples of typical calculation scenarios are given in B.7.

4.4.3 Voltage drop probability (risk)

The statistical basis of the Herman-Beta method implies the inclusion of uncertainty in the voltage drop calculation. This uncertainty is addressed by the application of a level of risk expressed as a percentage. A low risk value yields a safer design but will yield a higher calculated voltage drop that might be the basis for designing a more costly system. A high risk value leads to lower cost but might incur violation of the specified voltage range. Risk and its impact on design is being researched and the results will be published when available. Most probabilistic designs are based on a 10 % risk (90 % confidence level). Stated simply, this means that when the actual load reaches its design level, the designer is 90 % confident that all of the consumers will receive a voltage within the statutory limits (see NRS 048-2). The designer has the freedom to decide on the risk level.

4.4.4 Other sources of error in the voltage drop calculation

Apart from the risk of excessive voltage drop due to the statistical nature of the voltage drop algorithm, there are other possible sources of inaccuracy. The main ones occur in the input data used, and include

a) the assumed source voltage might be different from the actual voltage,

b) the differences between the load model used in the calculations and actual loads on the feeders, and

c) the inaccuracy of the network model, for example, inaccuracies in the estimates of conductor resistance.

These sources of potential error collectively give rise to a design-data confidence level or design-data uncertainty level (or both). It is difficult to make any recommendations on how to assess these sources of error.

4.5 Current-carrying capacity of LV distributors

The designer should take the current-carrying capacity of the distributors into consideration. The current capacity of a conductor can be obtained from the manufacturer.
The total expected current in a feeder is calculated automatically by the Herman-Beta algorithm. To determine the current per phase for more than ten connected consumers, the following slightly less accurate formula, based on the central limit theorem, may be used:

\[
N_p \times \frac{c}{a+b} \left[ a + 1,28 \left( \frac{a \times b}{N_p (a+b+1)} \right) \right]
\]

where

- \( N_p \) is the total number of consumers on the heaviest loaded phase;
- \( a, b, c \) are the load parameters.

The factor 1.28 is for a 10% risk.

4.6 Financial analysis of electricity projects

4.6.1 Financial analysis of alternative schemes or alternative equipment should take into account more than the initial cost. Operating, maintenance, upgrading, reinforcement and other “lifetime” costs have to be included in financial evaluations. Financial analysis is described in greater detail and further examples are given in annex C.

4.6.2 The following examples illustrate the calculation of the cost of transformer losses and of investment projects.

Example 1 — Cost of transformer losses

The capitalization of the cost of transformer losses estimates the financial value of future energy losses reflected at the time of purchase of the transformer. The net present value (NPV) of a transformer is given by

\[
N = A + C_0 P_0 + C_1 P_1
\]

where

- \( N \) is the net present value (NPV);
- \( A \) is the installed cost of the transformer, in rands;
- \( C_0, C_1 \) are the capitalized costs of no-load and load losses, per kilowatt of loss, in rands;
- \( P_0, P_1 \) are the no-load and load losses, in kilowatts.

Example 2 — Investment projects

The comparison of alternative schemes with different cash flows requires methods that take into account the time value of money. In most cases, payback period methods are mostly insufficient for accurate analysis. NPV analysis is recommended for the evaluation of investment projects.

For example, NPV analysis is useful in comparing the costs of a project that could be implemented in stages. If, at present, a project is carried out in one stage, the NPV of the project is equal to the actual cost. Alternatively, the project could be carried out in two stages, with stage 1 costing \( C_1 \) carried out immediately and stage 2 costing \( C_2 \) carried out in \( n \) years’ time. With a discount rate of \( i \% \) per year, and ignoring differences between the operating costs of the two alternatives, the NPV is given by
\[ N = C_1 + \frac{C_2}{(1 + i)^n} \]

The financially more beneficial option will be the one with the lower NPV.

4.7 Distribution system protection

4.7.1 Medium-voltage system protection

4.7.1.1 Feeder protection

The following types of feeder protection should be used:

a) for an underground cable system: non-directional inverse definite minimum time lag (IDMTL) overcurrent and earth fault protection;

b) for MV aerial bundled conductor systems: non-directional, extremely inverse overcurrent and earth fault protection (see NOTE 1 below); and

c) for a bare overhead conductor system: non-directional IDMTL overcurrent and earth fault protection plus sensitive earth fault protection with single shot or multishot auto-reclose facilities.

NOTE 1 This note is applicable to both 4.7.1.1 (a) and 4.7.1.1 (b). Extremely inverse overcurrent protection should be used where the fault level is high and the conductor size is small. This is typical of MV aerial bundled conductor systems near the supply source. The use of extremely inverse relays should also be considered in cases where discrimination with high rupturing capacity fuses is needed, or where a faster clearance time is needed.

NOTE 2 For systems where the MV earth fault current is limited, earth fault protection may be of the definite time delay type with delay times variable in the range 0 s to 10 s. In cases where the conductor is small, such as on MV aerial bundled conductor systems, special care should be taken to avoid excessive rises in temperature.

NOTE 3 It is essential that proper care be taken in the selection of current transformer ratios to ensure that the protection will operate correctly for the full range of fault currents that could appear on the feeder. In this regard, special attention should be given to very long feeders.

4.7.1.2 Distribution transformer MV protection (MV/LV transformer)

MV protection at A in figure 6 may comprise one of the following:

a) a high rupturing capacity fuse or expulsion fuse; or

b) two overcurrent a.c. trip coils with a time-lag fuse, or a circuit-breaker, or a relay with an unshunted a.c. earth fault trip coil; or

C) a link or an isolator, provided that the primary MV feeder protection will operate to clear a disruptive fault on the distribution transformer.

NOTE 1 For pole-mounted distribution transformers connected to a bare overhead or an MV aerial bundled conductor, surge arresters should be fitted and connected as close to the MV transformer bushings as possible. (NRS 039-1 gives guidance on the application of MV surge arresters.)

NOTE 2 A high rupturing capacity fuse is generally used in switchgear, whereas an expulsion fuse is used on overhead lines.
4.7.2 Low-voltage system protection

4.7.2.1 A typical low-voltage distribution system is shown in figure 6. Protection schemes applicable to underground cables, aerial bundled conductors or bare overhead conductor systems are as follows:

a) at B: fuse or circuit-breaker that provides overload protection for the transformer and fault protection for the LV busbars (see NOTE 1 to 4.7.2.2);

b) at C: fuse or circuit-breaker that provides overload and fault protection for the main LV distributor and service connection distribution box;

c) at D: fuse or circuit-breaker that provides fault protection for the service cable;

d) at E: fuse or circuit-breaker that provides overload protection for the service cable and the meter; and

e) at F: fuse or circuit-breaker that provides overload and fault protection for the consumer’s distribution board, in cases where the latter is supplied by the supply authority, for example, a ready board.
4.7.2.2 Usually it will not be possible to obtain discrimination with protection at all the positions shown. A realistic and more cost-effective system will be obtained if protection is omitted at one or more points, as follows:

a) protection may be omitted at B, provided that the MV protection at A will operate for a fault on the LV busbars and for a transformer overload;

b) protection may be omitted at C, provided that the protection at B will protect the outgoing feeders over their full length. This is particularly appropriate in the case of small LV systems supplied from a CSP transformer;

c) protection may be omitted at D or E, but not at both; or

d) protection may be omitted at F, provided that it is fitted at E (see (c) above).

NOTE 1 If a CSP transformer that complies with SANS 780 is used, protection is automatically provided at A and B.

NOTE 2 Attention should be given to the selection of protective devices to ensure that correct discrimination is obtained under both overload and fault conditions and that the devices are rated to withstand the maximum fault level imposed at the point of application.

NOTE 3 In some cases, protection is provided at F by the metering equipment. The protection requirements for the consumer's installation are given in SANS 10142-1.

4.7.2.3 Inherent in the protection of MV and LV systems is the requirement that all faults have to cause an overcurrent to operate the protection. For this reason, it is imperative that sound earthing principles are followed to provide a low-resistance earth path for all earth faults. In particular, the earthing of the LV systems should be in accordance with SANS 10292. In addition, circuit-breaker or fuse characteristics have to be appropriate for the expected fault characteristics. In cases where small transformers and conductors of small diameter are used, fault levels might be low and circuit-breakers need to be selected accordingly. Alternatively, the system should be designed to ensure that the minimum fault current will operate the circuit-breaker.

4.7.2.4 Guidelines for the protection design of LV systems for the overhead distribution systems covered by NRS 034-3 are given in annex D.

4.8 Earthing

4.8.1 General

The documents referred in 4.8.2 to 4.8.8, which are detailed in clause 2, cover aspects of earthing of electrical distribution systems.

4.8.2 Regulation 13 of the Electrical Machinery Regulations (see foreword)

Regulation 13 details the items of equipment at any premises that shall be earthed and also the responsibilities of the supply authority and the occupier or owner (or both) of the premises to correct such items that are found, during tests, not to be earthed.

4.8.3 SANS 10292

SANS 10292 covers the earthing of low-voltage (LV) distribution systems.

4.8.4 SANS 10142-1

A clause of SANS 10142-1 details the materials and methods that can be used for earthing during the wiring of premises, whether it be one room, or a block of offices, or flats. It also details the responsibilities and certification requirements of wiring contractors.
4.8.5 SANS 10198-3
SANS 10198-3 covers general provisions for the earthing of electric power cables and the apparatus in which the cables are terminated.

4.8.6 SANS 10198-5
SANS 10198-5 details the method of determining the thermal and electrical resistivity of soil in order to select the most suitable type(s) of earth electrode.

4.8.7 SANS 10198-12
SANS 10198-12 covers the installation of earthing systems. Reference is made to methods of providing an earth electrode. The earthing of metal cable components is covered in detail.

4.8.8 SANS 10199
SANS 10199 details methods used to design and install a suitable earth electrode and to reduce the earth resistance if, during post-installation tests, it is found to be too high.

4.9 Metering

4.9.1 Consumer metering
Metering of accuracy class 2 is recommended for all residential consumers.

In areas where meter reading and billing are preferred, the following alternatives are available:

a) ferraris induction type meters that comply with SANS 62052-11 and SANS 62053-21; and
b) static (electronic) type meters that comply with SANS 62052-11 and SANS 62053-21.

In areas where there is no infrastructure for billing consumers or for reading meters, or where it is preferable not to use credit metering, the use of electricity dispensers with a suitable vending infrastructure should be considered.

Electricity dispensers should comply with SANS 1524-1.

4.9.2 Statistical metering
The use of portable statistical metering equipment is recommended. Test metering and load modelling at regular intervals will indicate when and where a system requires upgrading.

5 Selection of equipment and materials

5.1 General
Equipment and materials should be selected from the ranges covered by the applicable national standards issued by Standards South Africa and, where applicable, by NRS specifications.

Preferred types and sizes of equipment and material for application in the electricity supply industry are covered by a series of NRS specifications that are detailed in clause 2 and in the bibliography.

All items selected should have characteristics that are appropriate to the conditions and to the parameters on which the design of the distribution system is based, particularly with regard to

a) the following electrical parameters, where applicable:
1) **voltage**: MV equipment and LV equipment, such as electricity dispensers, should be suitable for the maximum steady voltage likely to be applied and also for overvoltages that are likely to occur due to lightning;

2) **current**: the equipment should be suitable for the maximum steady r.m.s. current to be carried in normal service and for the current likely to be carried in abnormal conditions for the period (for example, the operating time of protective devices) during which it could be expected to flow;

3) **fault effects**: the design and arrangement of equipment should be such that fault damage is kept to a minimum, with graded protection and adequate earthing;

4) **electromagnetic compatibility**: equipment should not have a harmful effect on other equipment or on the supply during normal service. In this context, factors that can have an influence include power factor, inrush current, asymmetrical loads, harmonics and radio frequency voltages generated by equipment;

b) the following **mechanical parameters**, where applicable:

1) **factors of safety**: for example, the loads and tensions applied to poles, stays and fittings should be within the limits given in the design guides and, where applicable, national standards; and

2) **clearances**: the distance above ground and from fixed objects of equipment, in particular overhead cables or conductors, should be within the limits given in the design guides and, where applicable, national standards.

NOTE Guidance on the application of these parameters to the design of overhead lines is given in SANS 10280.

5.2 Selection of cables and conductors

5.2.1 General

When cables and conductors are being selected, some of the main points to be considered are

a) maximum operating current,

b) cyclic pattern of the current,

c) voltage drop,

d) short-circuit requirement,

e) exposure to mechanical damage,

f) lifetime costs, including the cost of losses,

g) earthing requirement,

h) current ratings, including derating factors,

i) possibility of theft of cable and energy, and

j) ability to withstand ultraviolet radiation.

For the preferred type of cable or conductor available within the ranges covered by the relevant SANS standards, see 4.3.6.
The permissible short-circuit current for a cable or conductor is determined by the maximum permissible conductor temperature and the duration of the short-circuit current, in other words, the time from the start of the short-circuit until it is broken by protective devices. The relevant formulas or tables and charts that list the maximum permissible short-circuit currents for different time intervals can be obtained from the cable manufacturers.

5.2.2 Fault currents and short-circuit ratings of cables

5.2.2.1 Fault current on the MV network

If the fault level in megavolt amperes is known, the fault current on the MV network is given by:

\[ I_f = \frac{P_f}{V_s \times \sqrt{3}} \]  

(5.1)

where

- \( I_f \) is the fault current, in kiloamperes;
- \( P_f \) is the MV fault level, in megavolt amperes;
- \( V_s \) is the MV system voltage, in kilovolts.

The size of the cable can then be checked against the manufacturer’s tables of short-circuit ratings for the expected fault clearance time.

Example:

For an MV fault level of 250 MVA, and an 11 kV three-phase system, the fault current is:

\[ I_f = \frac{250}{\sqrt{3} \times 11} = 13.12 \text{ kA} \]  

(5.2)

5.2.2.2 Fault level at the LV terminals of the transformer

The MV fault level should be taken into account in the calculation of the LV fault current at the transformer bushings. To allow for MV growth, use the maximum planned fault level at the step-down MV substation or the rating of that substation’s switchgear.

The formula for the fault level at the LV terminals is:

\[ I_f = \frac{1000}{\frac{1}{P_f} + \frac{Z_p \times 10}{T_r}} \times V_s \times \sqrt{3} \]  

(5.3)

A simplified formula which does not take the MV fault level into account (i.e. assumes an infinite MV bus) can be used. It gives an LV fault level around 5 % higher than when equation 5.3 is used. The simplified formula is:

\[ I_f = \frac{100 \times T_r}{Z_p \times V_s \times \sqrt{3}} \]  

(5.4)
where

- \( I_f \) is the fault current, in kiloamperes;
- \( P_f \) is the MV fault level, in megavolt amperes;
- \( Z_p \) is the transformer impedance, as a percentage;
- \( T_r \) is the transformer rating, in kilovolt amperes;
- \( V_s \) is the LV system voltage, in volts.

**Example:**

For an MV fault level of 250 MVA, an LV system voltage of 400 V and a transformer of 500 kVA and 5 % impedance, the fault current is:

\[
I_f = \frac{1000}{1 + \frac{1}{250} + \frac{5 \times 10}{500} \times 400 \times \sqrt{3}} = 13.88 \text{ kA}
\]  

Using the simplified formula, the calculated fault current would be 14.43 kA.

**5.2.2.3 Maximum fault current at service distribution points (SDPs)**

The three-phase fault level should be calculated at each node on the distributor where the cable size changes to allow checking whether the fault current rating of the cable from the SDP will be exceeded.

The impedance at the transformer LV terminals is mainly reactive, whereas the LV feeder impedances have both resistive and reactive components. For reasonable accuracy, the cable resistance and reactance both have to be taken into account.

The impedance at any point is the vector sum of the impedance up to the transformer LV terminals plus the sum of all LV feeder impedances. The feeder impedances should be taken at the same temperatures used for voltage drop calculations, i.e. 30 °C for underground cables and 40 °C for overhead lines and ABC.

The reactance up to the LV terminals, in ohms, referred to the LV side, is given by:

\[
X_s = \frac{V_s}{\sqrt{3} \times I_s \times 1000} \tag{5.6}
\]

where

- \( X_s \) is the reactance up to the LV terminals, in ohms;
- \( I_s \) is the three-phase fault current at the LV terminals, in kiloamperes;
- \( V_s \) is the LV system voltage, in volts. If the sum of the LV feeder impedances is \( R_l + jX_l \), then the total impedance, in ohms, is:

\[
Z_l = \sqrt{R_l^2 + (X_l + X_s)^2} = \sqrt{R_l^2 + \left( X_l + \frac{V_s}{\sqrt{3} \times I_s \times 1000} \right)^2} \tag{5.7}
\]
where
\[ R_f \] is the sum of the feeder resistances;
\[ X_f \] is the sum of the feeder reactances.

The three-phase fault current, in kiloamperes, is then given by:
\[
I_f = \frac{V_s}{\frac{1}{1000} \times Z_f} = \frac{V_s}{1000 \times \left( R_f^2 + X_f + \frac{V_s}{\sqrt{3} \times I_s \times 1000} \right)^2} \tag{5.8}
\]

Example:

For a fault level at the transformer LV terminals of 13.88 kA (see previous example) and a total LV feeder impedance of \((0.01299 + j 0.0061) \Omega\), the fault current in kiloamperes would be:
\[
I_f = \frac{400}{\sqrt{3} \times 1000 \times \left[ 0.01299^2 + \left( 0.0061 + \frac{400}{\sqrt{3} \times 13.88 \times 1000} \right)^2 \right]} = 8.82 \tag{5.9}
\]

5.2.2.4 Minimum fault level at ends of feeders

To ensure that fault protection devices operate successfully, the single-phase fault current at the end of each branch and at the consumer’s point of supply should be calculated. This is particularly significant in long, lightly loaded LV feeders. Since these feeders are longer than usual, their impedance \(Z\) rather than resistance only, should be used. The fault current should be larger than 1.6 times the full load current.

5.2.2.5 Standardized procedure for short-circuit calculations

Methods for the calculation of short-circuit currents are given in IEC 60909-0 and other standard texts. These methods can be applied to evaluate the maximum and the minimum short-circuit currents, in order to correctly select and adjust protection devices.

5.3 Selection of transformers

5.3.1 Networks should be so designed that the number of consumers to each transformer is optimized.

5.3.2 The following factors should be considered when transformers are being selected:

a) load density;

b) the limitations imposed by voltage drop considerations, taking into account the full range of available transformer tappings;

c) the cyclic nature of the load; and

d) the range of available transformer ratings.

5.3.3 Transformers should be selected from the standard ratings specified in SANS 780. For new designs, the standard no-load voltage specified in SANS 780 should be used. Transformers with non-standard no-load voltages and special tapping arrangements might be required in cases where extensions to existing networks are planned. See also table 1 for preferred ratings.
5.4 Use of energy-limiting circuit-breakers

Using energy-limiting circuit-breakers at the transformer in order to use underrated switchgear on subcircuits, for example, 2.5 kA moulded-case circuit-breakers (MCCBs) on a 15 kA fault level, should be done with caution.

Energy-limiting circuit-breakers are designed with a shorter tripping time than the circuit-breakers they protect, and protection grading might not be achieved. For example, on a subcircuit fault, the energy-limiting circuit-breaker will trip before the subcircuit circuit-breaker trips. However, circuit-breakers that limit the fault current and resulting stresses without immediate tripping might be suitable.

6 Inspection and tests

Before being energized, the system shall be inspected for compliance with legislation (see foreword), and with any other national or local regulations (see foreword). The system should also be inspected to ensure that all requirements for safety, labelling, and warning signs, etc., have been complied with, and that all poles carry identity discs.

All labels should be permanent, indelible and, where appropriate, of a size that is legible from ground level.
Annex A
(informative)

Arrangements for supplying a residential area

a) By arrangement with the supply authority, external supply may terminate:
1) inside residential area at A and B; or
2) outside residential area at A1 and B1.

b) External supply terminates at boundary of residential area (points A and B).

c) External supply terminates inside residential area at terminals of supply authority’s switchgear (points A and B).

d) External supply terminates at boundary of residential area (points A and B).

e) External supply terminates at boundary of residential area (points A and B).

f) External supply terminates at boundary of residential area (points A and B).

Key
Supply authority’s existing system
External supply
Medium-voltage internal network
Low-voltage internal network
Residential area boundary

Figure A.1 — Arrangements for supplying a residential area
Annex B
(informative)

Description and use of the Herman-Beta algorithm

B.1 List of symbols

The symbols used in the formulations in annex B were chosen to avoid Greek or other non-alphabetic symbols and, where possible, to avoid subscripts and superscripts. For example, ai is used rather than $\alpha_i$.

- $V_s$ is the nominal supply voltage, in volts;
- $a_i$ is the Beta probability density function parameter, alpha at node i;
- $b_i$ is the Beta probability density function parameter, beta at node i;
- $c_i$ is the scaling factor, in amperes (usually the circuit-breaker size) at node i;
- $m_{ai}$ is the number of consumers connected to the a-phase at node i;
- $m_{bi}$ is the number of consumers connected to the b-phase at node i;
- $m_{ci}$ is the number of consumers connected to the c-phase at node i;
- $C_{1i}$, $C_{2i}$, $C_{3i}$, $C_{4i}$, $C_{5i}$ and $C_{6i}$ and also $F_{1i}$, $F_{2i}$ and $F_{3i}$ are constants;
- $N$ is the total number of nodes in the radial feeder section;
- $R_p$ is the temperature-corrected resistance of the phase conductor per span;
- $R_n$ is the temperature-corrected resistance of the neutral conductor per span;
- $p$ is the percentage risk in the probabilistic calculation;
- $G$ is the first statistical moment;
- $H$ is the second statistical moment;
- $k_i$ is a resistance ratio;
- $R_i$ is a phase resistance index;
- $V_{max}$ is the maximum consumer voltage;
- $V_{min}$ is the minimum consumer voltage;
- $V_d$ is a voltage drop;
- $L$, $K$ are node counters;
- $V_c$ is the consumer voltage;
- $v_c$ is the normalized consumer voltage;
- $a_v$ is the alpha parameter of scaled consumer voltage;
- $b_v$ is the beta parameter of scaled consumer voltage;
- $\text{BETAIN}$ is the Beta inverse function;
- $D_{Vr_{maxi}}$ is the real component of maximum voltage drop at node i;
- $D_{vj_{maxi}}$ is the imaginary component of maximum voltage drop at node i;
- $D_{v_{mini}}$ is the minimum voltage drop at node i; and
- $E()$ is the expected value of ().
Annex B
(continued)

B.2 Step-wise procedure for calculating biphase system voltage drops
(for spreadsheet application)

B.2.1 Step 1 — Select the network parameters

B.2.1.1 Supply voltage, $V_s$.

B.2.1.2 Load description in Beta pdf form: $a_i$, $b_i$, $c_i$. Where $c_i$ is the scaling factor, it is usually the circuit-breaker size.

B.2.1.3 Specify the number of consumer connections at each load node, $i$: $m_{ai}$ and $m_{bi}$.

B.2.1.4 Specify the total number of nodes in the radial section, $N$.

B.2.1.5 Specify the phase and neutral conductor resistances for each section: $R_p$ and $R_n$, allowing for temperature rise.

B.2.1.6 Specify a design risk value: $p$, in percent.

B.2.2 Step 2 — Calculate constants $G_i$ and $H_i$

$$G_i = \frac{a_i}{a_i + b_i}$$

$$H_i = \frac{a_i(a_i + b_i)}{(a_i + b_i)(a_i + b_i + 1)}$$

B.2.3 Step 3 — Calculate $R_i$ and $k_i$

$$R_i = \sum_{j=1}^{i} R_n(j)$$

$$k_i = \frac{R_i}{\sum_{j=1}^{i} R_p(j)}$$

where

$R_n(j)$ is the neutral conductor resistance for section $(i - 1)$ to $(i)$;

$R_p(j)$ is the phase conductor resistance for section $(i - 1)$ to $(i)$. 
Annex B
(continued)

B.2.4 Step 4 — Calculate maximum and minimum voltages, Vmax and Vmin

\[
V_{\text{max}} = V_s + \sum_{i=1}^{N} V_{\text{imax}}
\]

\[
V_{\text{min}} = V_s - \sum_{i=1}^{N} V_{\text{imin}}
\]

where

- \(V_{\text{imax}}\) is \(k_i \times c_i \times m_{bi} \times R_i\)
- \(V_{\text{imin}}\) is \((1 + k)R_i \times c_i \times m_{ai}\).

B.2.5 Step 5 — Calculate the constants \(q_i\) and \(p_i\) and the expected values: \(E(V_i)\) and \(E(V_{d})\)

\[
p_i = c_i \times R_i \times m_{ai}(1 + k_i)
\]

\[
q_i = c_i \times R_i \times m_{bi} \times k_i
\]

\[
E(V_i) = G_i(q_i - p_i)
\]

\[
E(V_{d}) = \sum_{i=1}^{N} E(V_i)
\]

B.2.6 Step 6 — Calculate \(r_i\) and \(s_i\) and the expected values: \(E(V_i^2)\) and \(E(V_{d}^2)\)

\[
r_i = c_i^2 \times R_i^2 \left[ m_{bi} \times k_i^2 + m_{ai}(1 + k_i)^2 \right]
\]

\[
s_i = c_i^2 \times R_i^2 \left[ m_{bi}(m_{bi} - 1)k_i^2 - 2m_{ai} \times m_{bi}(k_i + 1)k_i + m_{ai}(m_{ai} - 1)(k_i + 1)^2 \right]
\]

\[
E(V_i^2) = r_i \times H_i + s_i \times G_i^2
\]

\[
E(V_{d}^2) = \sum_{i=1}^{N} E(V_i^2) = \sum_{K=1}^{N} E(V_{d,K}) \times E(V_{d,L})
\]

\[
L \neq K
\]
Annex B
(continued)

B.2.7 Step 7 — Calculate expected values \( E(V_c) \) and \( E(V_{c}^2) \)

\[
E(V_c) = V_s + E(V_d)
\]

\[
E(V_{c}^2) = V_s^2 + 2V_s \times E(V_d) + E(V_d^2)
\]

B.2.8 Step 8 — Calculate the scaled values of \( E(vc) \) and \( E(vc^2) \)

\[
E(vc) = \frac{E(V_c) - V_{\text{min}}}{V_{\text{max}} - V_{\text{min}}}
\]

\[
E(vc^2) = \frac{E(V_{c}^2) - 2V_{\text{min}} \times E(V_c) + V_{\text{min}}^2}{(V_{\text{max}} - V_{\text{min}})^2}
\]

B.2.9 Step 9 — Calculate the Beta parameters of \( (vc) \): \( a_v \) and \( b_v \)

\[
a_v = \frac{E(vc^2) - E(vc)}{E(vc) - E(vc^2)}
\]

\[
b_v = \frac{a_v}{E(vc)} - a_v
\]

B.2.10 Step 10 — Select a risk percentage \( p \) and calculate percentile value \( v_p \%

Use the Beta inverse function:

\[
v_p\% = \text{BETAIN}[p/100, a_v, b_v]
\]

B.2.11 Step 11 — Rescale the consumer voltage, \( V_{c\%} \)

\[
V_{c\%} = v_p\% (V_{\text{max}} - V_{\text{min}}) + V_{\text{min}}
\]

B.3 Step-wise procedure for calculating three-phase system voltage drops (for spreadsheet application)

B.3.1 Step 1 — Select the network parameters

B.3.1.1 Supply voltage, \( V_s \).

B.3.1.2 Load description in Beta pdf form: \( a_i, b_i, c_i \). Where \( i \) is the load node number and \( c_i \) is the scaling factor, usually the circuit-breaker size.
Annex B
(continued)

B.3.1.3 Specify the number of consumer connections at each load node, i: mai, mbi and mci.

B.3.1.4 Specify total number of nodes in the radial section, N.

B.3.1.5 Specify the phase and neutral conductor resistances for each section: Rp and Rn.

B.3.1.6 Specify a design risk value: p, in percent.

B.3.2 Step 2 — Calculate constants G and H

\[ G_i = \frac{a_i}{a_i + b_i} \]

\[ H_i = \frac{a_i(a_i + b_i)}{(a_i + b_i)(a_i + b_i + 1)} \]

B.3.3 Step 3 — Calculate Ri and ki

\[ R_i = \sum_{j=1}^{i} R_n(j) \]

\[ k_i = \frac{R_i}{\sum_{j=1}^{i} R_p(j)} \]

where

- \( R_n(j) \) is the neutral conductor resistance for section \((i - 1)\) to \(i\);
- \( R_p(j) \) is the phase conductor resistance for section \((i - 1)\) to \(i\).

B.3.4 Step 4 — Calculate maximum and minimum voltages, Vmax and Vmin

Real parts are indexed with r and imaginary parts with j. The symbol D is used to indicate voltage drop and i index indicates the i-th node.
Annex B
(continued)

\[
\begin{align*}
DV_{maxi} &= 0.5ki \times Ri \times ci(mbi + mci) \\
DV_{jmaxi} &= \frac{\sqrt{3}}{2} ki \times Ri \times ci(mbi - mci) \\
DV_{mini} &= (1+ki)Ri \times ci \times mai \\
V_{max} &= \sqrt{Vs + \sum_{i=1}^{N} DV_{rmaxi}} + \sqrt{\sum_{i=1}^{N} DV_{jmaxi}} \\
V_{min} &= Vs - \sum_{i=1}^{N} DV_{mini}
\end{align*}
\]

**B.3.5 Step 5 — Calculate the constants: C1i, C2i, C3i, C4i, C5i and C6i**

\[
\begin{align*}
C_{1i} &= (1+ki)mai - \frac{ki}{2}(mbi + mci) \\
C_{2i} &= ki^2[(mai + \frac{1}{4} mbi + \frac{1}{4} mci) + (2ki + 1)mai] \\
C_{3i} &= F_{1i} \times ki^2 + F_{2i} \times ki + F_{3i}
\end{align*}
\]

where

\[
\begin{align*}
F_{1i} &= mai(mai - 1) - mai(mbi + mci) + \frac{1}{4}(mbi + mci - 1)(mbi + mci) \\
F_{2i} &= mai(2mai - mbi - mci - 2) \\
F_{3i} &= mai(mai - 1) \\
C_{4i} &= \frac{3ki^2}{4}(mbi + mci) \\
C_{5i} &= \frac{3ki^2}{4}[(mbi - mci)^2 - (mbi + mci)] \\
C_{6i} &= \frac{\sqrt{3}}{2}ki(mbi - mci)
\end{align*}
\]
Annex B
(continued)

B.3.6 Step 6 — Calculate the expected values: \( E(Dvri) \), \( E(DVr) \), \( E(DV^2ri) \) and \( E(DV^2r) \)

\[
E(DVri) = C1i \times Ri \times ci \times Gi \\
E(DVr) = \sum_{i=1}^{N} E(DVri) \\
E(DV^2ri) = Ri^2 \times ci^2 \left[ C2i \times Hi + C3i \times Gi^2 \right] \\
E(DV^2r) = \sum_{i=1}^{N} E(DV^2ri) + \sum_{K=1}^{N} \sum_{L=1}^{N} E(DVr_K) E(DVr_L) \\
\text{L} \neq K
\]

B.3.7 Step 7 — Calculate expected values: \( E(DVji) \), \( E(DVj) \), \( E(DV^2ji) \) and \( E(DV^2j) \)

\[
E(DVji) = C6i \times Ri \times ci \times Gi \\
E(DVj) = \sum_{i=1}^{N} E(DVji) \\
E(DV^2ji) = Ri^2 \times ci^2 \left[ C4i \times Hi + C5i \times Gi^2 \right] \\
E(V^2j) = \sum_{i=1}^{N} E(DV^2ji) + \sum_{K=1}^{N} \sum_{L=1}^{N} E(DVj_K) \times E(DVj_L) \\
\text{L} \neq K
\]

B.3.8 Step 8 — Calculate \( E(Vc) \) and \( E(V^2c) \)

\[
E(Vc) = \frac{Vs}{1 - \frac{E(DVr)}{Vs}} + \frac{1}{2} \left( \frac{E(DV^2r)}{Vs} \right) \\
E(V^2c) = V_s^2 - 2Vs \times E(DVr) + E(DV^2r) + E(DV^2j)
\]
Annex B
(continued)

B.3.9  Step 9 — Calculate the scaled values of $E(v_c)$ and $E(v^2_c)$

Lower-case symbols are used to indicate the scaled values.

\[
E(v_c) = \frac{E(V_c) - V_{\min}}{V_{\max} - V_{\min}}
\]

\[
E(v^2_c) = \frac{E(V^2_c) - 2V_{\min} + V_{\min}^2}{(V_{\max} - V_{\min})^2}
\]

B.3.10  Step 10 — Calculate the Beta parameters of $(v_c)$: $a_v$ and $b_v$

\[
a_v = \frac{E(v_c^2) - E(v_c)}{E(v_c) - E(v_c^2)}
\]
\[
b_v = \frac{a_v}{E(v_c)} - a_v
\]

B.3.11  Step 11 — Select a risk percentage $p$ and calculate percentile value $v_p$

Use the Beta inverse function:

\[
v_p = \text{BETAIN}[p/100, a_v, b_v]
\]

B.3.12  Step 12 — Rescale the consumer voltage, $V_{c\%}$

\[
V_{c\%} = v_p (V_{\max} - V_{\min}) + V_{\min}
\]

B.4  Beta parameter relationships

B.4.1  Mean (average) value of Beta pdf parameters: $a$, $b$, and $c$

\[
\text{mean} = \frac{a}{a+b} \times c
\]

For load currents this would be equivalent to the ADMD, in amperes.

B.4.2  Standard deviation of a Beta pdf with parameters: $a$, $b$, and $c$

\[
\text{Std} = c \times \sqrt{\frac{ab}{(a+b)^2(a+b+1)}}
\]
Annex B

(continued)

B.4.3 Conversion from one base to another, i.e. from c1 to c2, given a1, b1 and c1

Then for a new base, c2

\[
a_2 = \frac{a_1 \times A}{b_1 c_2}
\]

\[
b_2 = A \times \frac{(A - c_1 + c_2)}{b_1 c_1 c_2}
\]

where

\[
A = a_1(c_1 - c_2) - b_1 c_2 + c_1 - c_2
\]

This conversion is valid for

\[
c_2 > \frac{a_1}{a_1 + b_1} \times c_1
\]

B.5 Representing a fixed power load in a Beta format

NOTE Fixed power loads, such as in the case of pump motors, may be represented by a Beta pdf. The constant power characteristic is also included in the model.

B.5.1 Single-phase load

A single-phase load with a constant power consumption of kVA_p at phase voltage V_p will draw a phase current of I_p, where \(I_p = 1000 \text{kVA}_p/V_p\).

Then the scaling factor of the current pdf is taken as \(c = 2000 \text{kVA}_p/V_p\) amps.

Factor \(S = 1.28 \sqrt{(4.5)/(V_{pu} + 2V_{pu}^2)}\); \(\sigma = I_p/S\) and \(Q = (cI_p - I_p^2 - \sigma^2)/(c\sigma^2)\)

Then \(\alpha = \beta = QI_p\)

NOTE (a) Fixed loads are considered to have unity power factor.

(b) \(V_{pu}\) is the per-unit voltage at the node to which the load is connected – thus an iterative calculation is required!

B.5.2 Three-phase load

A three-phase load with a total constant power consumption of kVA_3 at line voltage V_L will draw a line current of I_L amps, where \(I_L = 1000 \text{kVA}_3/(\sqrt{3}V_L)\).

Then the scaling factor of the current pdf on each phase is taken as \(c = 2000 \text{kVA}_3/(\sqrt{3}V_L)\) amps.

Factor \(S = \frac{1.28 \sqrt{4.5}}{(V_{pu} + 2V_{pu}^2)}\); \(\sigma = I_L/S\) and \(Q = (cI_L - I_L^2 - \sigma^2)/(c\sigma^2)\)
Annex B
(continued)

Then \( \alpha = \beta = Q_L \) on each phase.

NOTE \( V_{pu} \) is the per-unit voltage at the node to which the load is connected – thus an iterative calculation is required!

B.6 Mixing of two load types

Two load types belonging to two different statistical distributions with parameters, say \( a_1, b_1, c_1 \) and \( a_2, b_2, c_2 \) and present in the percentage ratio of \( a_1, b_1, c_1 \) denoted by \( \%_1 \), and in the percentage ratio of \( a_2, b_2, c_2 \) denoted by \( \%_2 \), respectively, may be combined at a load point. A new combined load type with parameters, say \( a_3, b_3 \) and \( c_3 \) may then represent the resulting aggregation. The scaling factor \( c_3 \) is taken as the larger of \( c_1 \) and \( c_2 \).

The first moments about the origin for the two load types are:

\[
\mu_1^{(1)} = \frac{a_1 \cdot c_1}{(a_1+b_1)}
\]

\[
\mu_2^{(1)} = \frac{a_2 \cdot c_2}{(a_2+b_2)}
\]

From this the combined first moment, \( \mu_3^{(1)} = [\%_1 \cdot \mu_1^{(1)} + \%_2 \cdot \mu_2^{(1)}] \)

The second moments about the origin are:

\[
\mu_1^{(2)} = \frac{a_1 \cdot (a_1+1) \cdot c_1}{(a_1+b_1)(a_1+b_1+1)}
\]

\[
\mu_2^{(2)} = \frac{a_1 \cdot (a_2+1) \cdot c_2}{(a_2+b_2)(a_2+b_2+1)}
\]

From this the combined second moment, \( \mu_3^{(2)} = [\%_1 \cdot \mu_1^{(2)} + \%_2 \cdot \mu_2^{(2)}] \)

The variance of the combined load is:

\[
\sigma_3^2 = \mu_3^{(2)} - (\mu_3^{(1)})^2
\]

Then \( a_3 = \mu_3^{(1)} \cdot q \) and \( b_3 = \frac{a_3 - \mu_3^{(1)}}{q} \)

where

\[
q = \frac{c_3 \mu_3^{(1)} - \mu_3^{(2)} - \sigma_3^2}{c_3 \sigma_3^2}
\]

B.7 Using worksheets for calculating voltage drop in feeders

B.7.1 General

Worksheets for calculating voltage drop are available from the NRS Project Manager. For details, access the NRS web page www.nrs.eskom.co.za, or telephone (011) 651-6846. Hand calculation using the Herman-Beta method is not recommended. Table B.1 shows a typical worksheet.
Annex B

(continued)

Table B.1 — Typical worksheet for calculating voltage drop

<table>
<thead>
<tr>
<th>Results</th>
<th>Red</th>
<th>White</th>
<th>Blue</th>
</tr>
</thead>
<tbody>
<tr>
<td>%tile Vcon</td>
<td>230.28</td>
<td>195.67</td>
<td>231.83</td>
</tr>
<tr>
<td>Voltage drop</td>
<td>-0.12</td>
<td>14.92</td>
<td>-0.80</td>
</tr>
<tr>
<td>%tile Isum</td>
<td>78.24</td>
<td>116.62</td>
<td>52.61</td>
</tr>
<tr>
<td>Mean Isum</td>
<td>65.65</td>
<td>98.66</td>
<td>43.65</td>
</tr>
<tr>
<td>Stdev Isum</td>
<td>9.78</td>
<td>13.84</td>
<td>6.95</td>
</tr>
<tr>
<td>Count</td>
<td>9.00</td>
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</tr>
<tr>
<td>Nodes</td>
<td>6.00</td>
<td>6.00</td>
<td>6.00</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>CABLES</th>
<th>°C</th>
<th>Code</th>
</tr>
</thead>
<tbody>
<tr>
<td>t1</td>
<td>20</td>
<td>ABC5</td>
</tr>
<tr>
<td>t2</td>
<td>20</td>
<td>ABC10</td>
</tr>
</tbody>
</table>

B.7.2 Voltage profiles

Subject to allocation of consumers to phases on a feeder, the largest voltage drop might not occur at its extremity. It is recommended that the last three nodes be examined for maximum voltage drop. This is done in the following way:

Consider the arrangement shown in figure B.1. The phase assignment at each node is given, starting with the red phase. Complete the entries for all the nodes as shown in table B.1. The calculated voltages on the phases as well as the percentage voltage drop will be indicated. These values are for the last node (F). To calculate the voltages at node E, the four consumers on the red phase at node F are added to those at node E: i.e. node F is eliminated and the loading on E becomes 4,4,0. This will give the voltage at node E. The process is repeated for further upstream nodes.

![Figure B.1 — Checking for maximum voltage drop](image)
B.7.3 Dealing with branched feeders

Figure B.2 shows an example of a typical branched network often encountered in practical distribution circuits. Voltage drops are required to be calculated for the main feeder (0-1-2-3-4) and for the spur (2-5-6). This can be done by firstly considering the main feeder section (0-1-2-3-4) and adding the total number of consumers per phase connected to the phases of the spur (2-5-6). This means that at node 2 we now have (1+1+1 = 3) on the a-phase, (2+1+2 = 5) on the b-phase and (1+2+1 = 4) on the c-phase. The loading on the rest of the nodes remains the same.

To deal with the spur (2-5-6) we lump the loads of 3 and 4 at node 2 and then, considering the section (0-1-2-5-6), we calculate the voltage drops as before.

B.8 Benchmark tests for software using the Herman-Beta algorithms

B.8.1 Group A benchmarks

B.8.1.1 General

This group of tests is selected to illustrate the perturbation in voltage drop caused by adjustment of certain parameters while the other parameters remain fixed. A total of 24 cases are examined; 12 each for the biphasic and three-phase topologies. In each case, 24 consumers are fed from the feeder. This presupposes that there are two types of plot layout, as shown in figure B.3. The sending end voltage in all cases is 230 V phase-to-neutral.
Annex B
(continued)

Figure B.3 — Benchmark networks for 24 consumers

B.8.1.2 Loads

Load pdfs may be skewed to the right or to the left. The loads used in these benchmark tests and their parameters are shown in table B.2

Table B.2 — Load types

<table>
<thead>
<tr>
<th>Type</th>
<th>a</th>
<th>b</th>
<th>c</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>L1</td>
<td>1,65</td>
<td>7,370</td>
<td>60</td>
<td>11</td>
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<tr>
<td>L2</td>
<td>3,50</td>
<td>2,860</td>
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<td>0,60</td>
<td>0,491</td>
<td>10</td>
<td>5,5</td>
</tr>
</tbody>
</table>

B.8.1.3 Phase assignment

Consumers may be connected to different phases in accordance with a predetermined pattern. These connection patterns may be termed “cosine” or “cyclic”.

Connections red, yellow, blue, blue, yellow, red, for example, are connected according to a “cosine” pattern while red, yellow, blue, red, yellow, blue, is an example of a “cyclic” pattern. In the designation cos 211 the implication is a three-phase, “cosine” arrangement with the two consumers on one phase and one consumer on each of the other phases. An example of a biphas designation is cyc 40 or bal 22 (i.e. two consumers per “phase”).

B.8.1.4 Line resistance

The distance between nodes is assumed to be equal and the phase conductor resistance per section is taken as a typical practical value of 0,027 Ω at 20 °C. The ratio of the neutral-to-phase resistance is k and is taken as either 1,0 or 1,4. Operating temperatures of 20 °C and 60 °C for the conductors are considered.
Annex B
(continued)

B.8.1.5 Design risk

Quantile values of voltage drop depend on the choice of risk (alternatively, the level of confidence) in probabilistic calculation methods. Two values of risk are considered: 10 % and 20 %.

B.8.2 Group B benchmarks

The group A tests (see tables B.3, B.4 and B5) investigate the effects that parameter variation has on the voltage performance of networks with identifiable topology and load connection patterns. In the group B tests (see table B.6) the emphasis is on the effect that randomness has on voltage drops in a network. Domestic consumer load types are given in table B.7. Six cases are investigated for this purpose.
Annex B
(continued)

Table B.3 — Group A benchmark test specifications

<table>
<thead>
<tr>
<th>Test</th>
<th>Connections</th>
<th>Load</th>
<th>Risk %</th>
<th>Temperature °C</th>
<th>( k )-ratio</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Biphase, 24 consumers</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>6 Nodes</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Bal 22</td>
<td>L1</td>
<td>10</td>
<td>20</td>
<td>1.0</td>
<td>Best case for biphase</td>
</tr>
<tr>
<td>2</td>
<td>Single-phase</td>
<td>L3</td>
<td>10</td>
<td>20</td>
<td>1.0</td>
<td>Compare with test #24 : same results</td>
</tr>
<tr>
<td><strong>8 Nodes</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Cos 30</td>
<td>L1</td>
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<td>20</td>
<td>1.0</td>
<td>Compare #4 - effect of ( k )</td>
</tr>
<tr>
<td>4</td>
<td>Cos 30</td>
<td>L1</td>
<td>10</td>
<td>20</td>
<td>1.4</td>
<td>Compare #3 - effect of ( k )</td>
</tr>
<tr>
<td>5</td>
<td>Cyc 30</td>
<td>L1</td>
<td>10</td>
<td>20</td>
<td>1.0</td>
<td>Compare #3 - effect of cyclic : cosine</td>
</tr>
<tr>
<td>6</td>
<td>Cyc 30</td>
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<td>60</td>
<td>1.0</td>
<td>Compare #5 - effect of temperature</td>
</tr>
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<td>7</td>
<td>Cos 21</td>
<td>L1</td>
<td>10</td>
<td>20</td>
<td>1.0</td>
<td>Compare #3 - improved balance at each node</td>
</tr>
<tr>
<td>8</td>
<td>Cos 21</td>
<td>L2</td>
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<td>20</td>
<td>1.0</td>
<td>Demand limited load, same mean as #7</td>
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<td>9</td>
<td>Cos 21</td>
<td>L3</td>
<td>10</td>
<td>20</td>
<td>1.0</td>
<td>Light load: mean = 5.5 A, alpha &lt; 1</td>
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<tr>
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<td>Cyc 21</td>
<td>L1</td>
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<td>20</td>
<td>1.0</td>
<td>Compare #7 - effect of cyclic : cosine</td>
</tr>
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<td>Cyc 21</td>
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<td>1.0</td>
<td>Compare #10 - effect of risk</td>
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<td>L3</td>
<td>10</td>
<td>20</td>
<td>1.0</td>
<td>Compare with #14 : same results</td>
</tr>
<tr>
<td><strong>Three-phase, 24 consumers</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8 Nodes</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>Bal 111</td>
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<td>20</td>
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<td>14</td>
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<td>L3</td>
<td>10</td>
<td>20</td>
<td>1.0</td>
<td>Compare with test #12 : same results</td>
</tr>
<tr>
<td>6 Nodes</td>
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<td></td>
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<td></td>
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</tr>
<tr>
<td>15</td>
<td>Cos 400</td>
<td>L1</td>
<td>10</td>
<td>20</td>
<td>1.0</td>
<td>Compare #16 - effect of ( k )</td>
</tr>
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<td>16</td>
<td>Cos 400</td>
<td>L1</td>
<td>10</td>
<td>20</td>
<td>1.4</td>
<td>Compare #15 - effect of ( k )</td>
</tr>
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<td>17</td>
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<td>L1</td>
<td>10</td>
<td>20</td>
<td>1.0</td>
<td>Compare #15 - effect of cyclic : cosine</td>
</tr>
<tr>
<td>18</td>
<td>Cyc 400</td>
<td>L1</td>
<td>10</td>
<td>60</td>
<td>1.0</td>
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</tr>
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<td>19</td>
<td>Cos 211</td>
<td>L1</td>
<td>10</td>
<td>20</td>
<td>1.0</td>
<td>Compare #15 - improved balance at each node</td>
</tr>
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</tr>
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<td>21</td>
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<td>Compare #2 - same results</td>
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### Table B.4 — Percentage voltage-drop calculations for group A, biphase tests

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<th>Test</th>
<th>Node</th>
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<th>5</th>
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<tbody>
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<td></td>
<td></td>
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</table>
Table B.5 — Percentage voltage-drop calculations for group A, three-phase tests

<table>
<thead>
<tr>
<th>Node</th>
<th>Phase (r = red phase, y = yellow phase, b = blue phase)</th>
<th>Test</th>
<th>Node</th>
<th>Phase (r = red phase, y = yellow phase, b = blue phase)</th>
</tr>
</thead>
<tbody>
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Annex B
(continued)

Table B.6 — Percentage voltage-drop calculations for group B tests

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<tr>
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<tr>
<td>30</td>
<td>2.37</td>
<td>2.37</td>
</tr>
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</table>

Case 1, Test 25: Three-phase, four-wire network with uneven node spacing (see figure B.4)

For this case a standard resistance of 0.868 \( \Omega \) per kilometre is used and the distances between the nodes are given in metres. A cos 400 consumer assignment is used. The neutral-to-phase resistance ratio is taken as 1 and the load type L1 is assumed for all consumers. The following lengths are specified between nodes: A-B: 50 m; B-C: 125 m; C-D: 70 m; D-E: 45 m; E-F: 225 m and F-G: 170 m.

Case 2, Test 26: Three-phase, four-wire network with even spacing but unbalanced phase allocation (see figure B.4)

The same conductor is used throughout with characteristic resistance of 0.868 \( \Omega \) per kilometre, \( k \) equals 1, and the distance between nodes is fixed at 50 m. Consumer allocations on the phases at each node are: B: 5,1,4; C: 1,2,1; D: 1,2,2; E: 1,1,3; F: 4,2,5 and G: 2,1,1. Loads are all type L3.

Case 3, Test 27: Three-phase, four-wire network with uneven spacing and unbalanced phase allocation (see figure B.4)

In this case the conductor type and node spacing are the same as case 1 and the consumer allocation is unbalanced. The consumer allocations chosen for this case are: B: 1,0,0; C: 0,1,5; D: 2,0,2; E: 3,4,2; F: 1,0,0 and G: 0,3,0. Load type is L3.

Case 4, Test 28: Three-phase underground system with distribution kiosks feeding current limited loads (see figure B.5)

This case investigates a typical underground low-voltage distribution system where twelve-way distribution kiosks are used. Phase and neutral resistances per kilometre are 0.443 \( \Omega \). The first two kiosks have four consumers per phase and the last seven consumers are allocated in a 2,2,3 arrangement. Load type L2 is chosen for this case. The system layout is shown in figure B.5.
Case 5, Test 29: Three-phase spine with two single-phase spurs

This case examines the arrangement shown in figure B.6.

The 70 mm² conductor linking nodes A, B, C and D is a three-phase four-wire feeder with a characteristic resistance of 0.443 Ω/km. The neutral-to-phase resistance ratio, \( k \), is taken as 1.4. Conductor sizes for the single-phase spurs (B-E-F and D-G-H) are all 35 mm² with a characteristic resistance of 0.868 Ω/km. The distances between the nodes are shown as are the phase allocations of consumers. All loads are type L3.

Case 6, Test 30: Biphase spine with two single-phase spurs (see figure B.7).
Annex B

(continued)

This case is similar in respects to the previous case, as can be seen from figure B.7. The only difference is that the spine, A-B-C-D, is a two-conductor, biphase feeder of the same size as the three-phase spine in case 5. Because it is a biphase system, the phase allocations at nodes B, C, D are all 2,2. Loads are all of type L3. The results for the group B tests are given in table B.6.

Table B.8 shows that the mixed load may be modelled as having alpha = 1,387, beta = 2,647 and the larger of the two circuit-breaker sizes is cb = 20 A.

The 15 kVA load is converted to a Beta equivalent load using the algorithms developed for fixed loads, and the results of the P-Q load conversion is shown in table B.9.

B.9 Verification of mixed and fixed loads

Figure B.8 shows the single-line diagram of the test case. The 70 mm$^2$ conductor linking the nodes A, B, C and D is a three-phase four-wire feeder with characteristic resistance of 0.443 Ω per kilometre. The neutral-to-phase resistance ratio, $k$, is taken as 1.4. Conductor sizes for the single-phase spurs (B-E-F and D-G-H) are all 35 mm$^2$ with a characteristic resistance of 0.868 Ω per kilometre. The distances between the nodes are shown, as are the phase allocations of consumers. All loads are type L3 on nodes B, E, C and D; 25 % type L2 and 75 % type L3 on nodes G and H; on node F the P-Q fixed load is 15 kVA.

The results of the Herman-Beta calculations (confirmed by Monte-Carlo simulation) are shown in table B.10.

![Network diagram](image)

**Table B.7 — Domestic consumer load types**

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<thead>
<tr>
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<th>2</th>
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<td>Type</td>
<td>a</td>
<td>b</td>
<td>c</td>
<td>Mean A</td>
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<td>L1</td>
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<td>7,370</td>
<td>60</td>
<td>11</td>
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<tr>
<td>L2</td>
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<td>2,860</td>
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<td>20</td>
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<td>L3</td>
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### Annex B

(continued)

#### Table B.8 — Results of worksheet mixing algorithm

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<td><strong>Input</strong></td>
<td><strong>Result</strong></td>
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<td>0,491</td>
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#### Table B.9 — Results of P-Q load conversion

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</tr>
<tr>
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</tr>
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<td>A</td>
</tr>
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</tr>
<tr>
<td>Beta</td>
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</tr>
<tr>
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#### Table B.10 — Results of Herman-Beta calculations

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<td><strong>%tile Isum</strong></td>
<td><strong>Mean Isum</strong></td>
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Annex C
(informative)

Financial analysis

C.1 Introduction

Economic considerations are important in the evaluation of the desirability of different projects with different cash flows (investment and income) over the lifetime of the project. For example, the time value of money needs to be taken into account in comparisons of a high first cost, low maintenance project with alternatives that provide a technically comparable solution.

The basis of lifetime costing is the conversion of “discounting” of all future income and expenditure to the “present value”. The net present value (NPV) of a project is the algebraic sum of initial costs, and discounted future costs and income. A project with a positive NPV is viable and the project with the highest NPV is the most profitable.

The method of financial analysis given in this annex is based on the concept that an investor will be indifferent as to whether he receives R100 now and invests it with a return of 10 % per year or whether he receives R110 in a year’s time.

C.2 Calculation of present value (PV)

The price of an item or service in \( n \) years’ time is:

\[
C_n = (1 + i)^n
\]

where

- \( C_n \) is the cash flow in \( n \) years’ time, expressed in current prices, as if expended today;
- \( i \) is the inflation rate (per unit per year);
- \( n \) is the number of years;

The present value (PV) of a future income or expense in year \( n \) is given by:

\[
PV = C_n \left[ \frac{1 + i}{1 + d} \right]^n
\]

where

- \( d \) is the discount rate (per unit per year).

NOTE 1 Per unit (p.u.) is the value of the annual percentage divided by 100, for example 12 % per year becomes 0,12.

NOTE 2 The discount rate, also known as the required rate, cut-off rate, target rate or cost of capital, is the assumed minimum desired rate of return. All expected future cash flows are discounted to the present by applying the above equation.

For example, if the value of \( i \) is 0,12 (12 % per year) and the value of \( d \) is 0,2 (20 %), then payment in two years’ time for something that costs R200 at current (today’s) prices, is equivalent to receiving the present value now:
Annex C
(continued)

The factor \( r - 1 \) is called the net discount rate, which should not be confused with the net discount rate \( d \), from which equation (C.1) can be simplified by using \( r = \frac{1 + d}{1 + i} \) to give:

\[
PV = \frac{C_n}{r^n} = C_n r^{-n}
\]  
(C.2)

The PV of an expense incurred every year (such as an annuity), that inflates at \( i \) per year and is discounted at rate \( d \), is:

\[
PV = C_a \frac{r^n - 1}{r^n(r-1)}
\]  
(C.3)

where

\( C_a \) is the annual cash flow in each of \( n \) years, expressed in current prices;

\( r \) is the net discount rate \((\text{p.u.}) + 1\).

For example, the PV of a maintenance expense, expressed in current prices of R1 000 per year in each of the next three years, where the net discount rate is 8 %, can be calculated as follows:

\[
PV = \frac{1000 \cdot (1.08^3 - 1)}{1.08^3 (1.08 - 1)} = 2577
\]

Usually, evaluation is simplified by using the net discount rate instead of separate inflation and discount rates. This assumes that the costs of components of the cash flow projection do not change in relation to other components in the analysis. If some prices are changing in relation to other prices, the discount and inflation rates have to be modified. All inflation and discounting can be treated separately, or inflation can be expressed in relative terms, using the net discount rate. As long as both rates are expressed in the same way (such as including or excluding general inflation), the resulting PV will be the same. The PV should be determined from a stream of costs discounted at a net discount rate, unless significant differences in the inflation rates of different components are expected to arise in the period being analysed. A fixed amount received or paid in \( n \) years’ time without taking inflation into account, such as a payment defined in a contract, has a PV of:

\[
PV = C_n [1 + d]^{-n}
\]

Since the inflation of this component is zero, its analysis in a stream of costs discounted at a net discount rate will take the inflation rate into account. Therefore, expressed in terms of \( r \) and \( i \), the present value PV is:

\[
PV = C_n r^{-n}[1+i]^{-n}
\]
C.3 Selection of the net discount factor

The calculation of the present value requires the use of a discount rate that reflects the opportunity cost of capital. In developed countries, where investment risks are relatively low and capital is readily available, net discount rates of 3 % to 6 % are commonly adopted. However, developing countries have a scarcity of capital – a key constraint on development in these countries. Also, investment risks are relatively high.

The South African Central Economic Advisory Service (a department of the Treasury) requires a minimum rate of return of 8 % in real terms to justify capital investment projects in South Africa. Higher real rates of return, for example 10 % or even as much as 15 %, are recommended where there are serious constraints on the availability of capital.

The net discount rate is not the real rate of interest (i.e. interest rate minus inflation rate), although the real interest rate can, for short periods, be similar to the net discount rate. Net discount rates generally exceed the real interest rate, which itself exceeds zero in stable economic circumstances.

The net discount rate does not consist of components related separately to interest and risk. It is a composite indicator of the opportunity cost of capital. Financial risk can be assessed by a sensitivity analysis, using price changes in costs and benefits and modified projections to ascertain the range of possible outcomes.

A net discount rate of 8 % to 10 % is recommended by the World Bank and should be used in present value analyses of electricity projects in South Africa.

C.4 Financial and economic analyses

There is a difference between a financial and an economic analysis.

A financial analysis uses existing and projected market prices to evaluate benefits and costs. It is based on cash flow and is entirely quantitative. Financial analysis is an assessment from the viewpoint of the purchaser.

An economic analysis adjusts market prices which are distorted by factors such as price control, taxes or unemployment, to their true value in the economy. The elements of a financial analysis which are modified in an economic analysis can include unskilled labour, fuel and the cost of land.

The details of these modifications fall outside the scope of this annex. However, their relevance is indicated in the following simple example. Where diesel fuel is subsidized, supply from an unsubsidized network connection might not appear to the user to be competitive with a diesel-driven supply on a lifetime basis (financial analysis using the market cost of fuel). However, from an economic analysis, where the cost of fuel without a subsidy is used, the network supply can be economical for the country. The user would normally choose the diesel-driven supply, but his choice could be influenced by the application of an equivalent subsidy for the network alternative.

Economic analysis is important in energy policy formulation, but is less significant for a supply utility or a consumer constrained to operate according to market prices.

C.5 Scope of analysis

In a major analysis, it is necessary to take into account

a) the capital investment costs,

b) all energy purchases and sales, and
c) all operating, administrative and maintenance costs

incurred over the lifetime of the project. Unless inconsistent with the application, projects should be evaluated over 20 years or 25 years, since this is the average economic life of distribution equipment. Beyond 25 years, there is generally little significant effect. The NPV of the project will reflect its desirability.

In a more restricted analysis, only the marginal capital investment and incremental cash flows need be considered. An analysis of this type is illustrated in C.6. If the project is expected to show a short-term return, it can be assessed by a discounted payback period, instead of an analysis over 20 years.

In evaluating two alternatives that have different conditions at the end of the evaluation period, it might be necessary to estimate the value of the continued use of the asset. In an extreme but simple example, the use of entirely consumed materials such as candles, compared with connection to a network, will be based on the lifetime of the network. If, in this example, the comparison is made over a shorter period, a value will be assigned to the remaining value of the network assets. Another situation arises more frequently where a major investment can be deferred, but not replaced, by a temporary alternative scheme with a useful life of only two to seven years, after which the same major investment is required. In this case, the deferred investment should be given a residual value at the end of the evaluation period, for example 20 % of its current price, to represent its unutilized capacity for generating further returns.

NOTE The cost of losses in cables is covered in IEC 60287-3-2.

C.6 Financial analysis examples

C.6.1 Analysis of incremental cash flow

C.6.1.1 Problem

A supply system is being planned. There are two options:

a) to invest R2 million now; or

b) to invest R1,5 million now and R800 000 (in today's terms) in seven years' time.

The difference in losses and other performance aspects is negligible and can be ignored. Which investment option is more attractive if the net discount rate is 8 % per year?

C.6.1.2 Analysis

Eliminate the common costs so that the options are reduced to

a) spending R500 000 now, or

b) spending R800 000 in seven years' time.

The present value of option (b) is:

\[
\frac{800\,000}{(1+0.08)^7} = R466\,792
\]

Therefore, it is attractive to defer the expenditure for seven years.
A sensitivity analysis shows that if the deferred expenditure were to exceed R857 000 (in today’s terms), the alternative decision would be more attractive. The risk of the expenditure exceeding the break-even amount needs to be assessed in risk analysis, quite separately from the financial model.

C.6.2 Discounted payback period

C.6.2.1 Problem

An expenditure of R20 000 now will reduce annual maintenance costs by R4 200 per year. The simple payback period is 4.76 years. What is the discounted payback period, if the net discount rate per year is 8 %? Table C.1 gives an analysis of present cost and value and the cumulative PV.

C.6.2.2 Analysis

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<th>Year 1</th>
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<th>Year 7</th>
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<td>4 200</td>
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<td>4 200</td>
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<td>2 858</td>
<td>2 647</td>
<td>2 450</td>
</tr>
<tr>
<td>Cumulative PV</td>
<td>3 889</td>
<td>7 490</td>
<td>10 824</td>
<td>13 911</td>
<td>16 769</td>
<td>19 416</td>
<td>21 866</td>
</tr>
</tbody>
</table>

Therefore, the discounted payback period is approximately 6.24 years.

This analysis, being a constant annual sum (in present terms), could be treated as an annuity. Where the annual sum changes, the tabular layout is necessary.

NOTE The relationship (where there is an annuity) between the simple and the discounted payback period, say \( y \) and \( n \) respectively, can be derived from equation (C.3) and is:

\[
\log\left(\frac{1}{1 - y(r - 1)}\right) = \log\frac{1}{1 - 10(1.08 - 1)} = 20.9\text{ years}
\]

C.6.3 Cost of transformer losses

C.6.3.1 Problem

Assume that the maximum load on a transformer in a new installation will increase over five years and then remain constant for the next fifteen years. What is the value of the losses?
C.6.3.2 Analysis

The no-load losses will be constant, but the load losses will increase with the load. The cash flow is modelled in table C.2 for a typical distribution transformer. Under the conditions illustrated, the cost of no-load losses is R7 481/kW and that of load losses is R2 295/kW of the rated loss. These costs per kilowatt are independent of the rating and losses of the transformer but depend on the load conditions modelled, in particular the loading and loss load factors and the tariff for demand and energy.

The loss load factor is the ratio of actual energy in relation to the load losses under typical loading conditions to the relevant energy losses that would occur if the transformer was fully loaded at all times. The loss load factor $LLF$ is empirically related to the load factor $LF$ by the relation:

$$LLF = aLF + (1−a)LF^2$$

where

- $a$ typically has a value of between 0.1 and 0.4.

Research is being done on typical loss load factors for distribution. The costs of losses can be used as capitalization factors in evaluating different transformers.

This type of model can also be used to evaluate the extra losses incurred when a transformer is overloaded.

If two transformers with power ratings of 100 kVA and 200 kVA respectively and that comply with SANS 780, are loaded in the same way to a load of 160 kVA, the NPV of the extra losses of the smaller transformer is about R7 800. This extra cost should be offset against the initial saving derived from the smaller transformer.

NOTE The PV per kilowatt of load loss on the 100 kVA transformer is R9 182 when the transformer is loaded to 160 % of its rating.

C.6.4 Losses in a network

C.6.4.1 Problem

The implementation cost of a particular distribution network was estimated to be R14 560 lower than that of an alternative. The annual repayment on this amount was given as R2 326.

The additional losses related to the lower cost design were estimated to cost R1 815 per year once the system is fully loaded.

The apparent saving by adopting the lower cost installation is R511 per year. However, if energy costs increase by 10 % per year, the saving will disappear in year four. However, the cost of additional losses in the first three years is only 25 %, 50 % and 75 % because the system is not yet fully loaded.

Assuming a net discount rate of 9 % and a life of 20 years, which installation is financially more attractive?
Annex C
(continued)

Table C.2 — Cost of losses of a distribution transformer

<table>
<thead>
<tr>
<th>Year</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
</tr>
</thead>
<tbody>
<tr>
<td>Load (p.u.)</td>
<td>0,216</td>
<td>0,4</td>
<td>0,56</td>
<td>0,696</td>
<td>0,8</td>
<td>0,8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Loss load factor</td>
<td>0,23</td>
<td>0,25</td>
<td>0,27</td>
<td>0,29</td>
<td>0,31</td>
<td>0,33</td>
<td></td>
<td></td>
</tr>
<tr>
<td>No-load loss (kW)</td>
<td>0,5</td>
<td>0,5</td>
<td>0,5</td>
<td>0,5</td>
<td>0,5</td>
<td>0,5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>No-load energy (kWh)</td>
<td>4 380,0</td>
<td>380,0</td>
<td>4 380,0</td>
<td>4 380,0</td>
<td>4 380,0</td>
<td>4 380,0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Load loss (kW)</td>
<td>0,11</td>
<td>0,37</td>
<td>0,72</td>
<td>1,11</td>
<td>1,47</td>
<td>1,47</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Load energy loss (kWh)</td>
<td>216,21</td>
<td>805,92</td>
<td>1 705,97</td>
<td>2 830,40</td>
<td>3 997,36</td>
<td>4 255,26</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

| No-load costs | Demand | 162,00 | 162,00 | 162,00 | 162,00 | 162,00 | 162,00 | 3 740,71 |
|               | Energy  | 219,00 | 219,00 | 219,00 | 219,00 | 219,00 | 219,00 | 7 481,43 |
|               | Total   | 381,00 | 381,00 | 381,00 | 381,00 | 381,00 | 381,00 |      |
|               | PV      | 352,78 | 326,65 | 302,45 | 280,05 | 259,30 | 81,74  |      |
|               | PV/kW of no-load loss | | | | | | | 3 740,71 |
| Load costs    | Demand  | 34,77  | 119,23 | 233,69 | 360,99 | 476,93 | 476,93 |      |
|               | Energy  | 10,81  | 40,30  | 85,30  | 141,52 | 199,87 | 212,76 |      |
|               | Total   | 45,58  | 159,53 | 318,99 | 502,51 | 676,80 | 689,69 |      |
|               | PV      | 42,20  | 136,77 | 253,23 | 369,36 | 460,52 | 147,97 | 5 279,92 |
|               | PV/kW of load loss | | | | | | | 2 295,62 |

NOTE 1 Years 6 to 19 have been calculated but, to save space, they have not been included in the table.

NOTE 2 Factors used in this table:
Transformer rating: 160 kVA
No-load loss: 0,5 kW
Rated load loss: 2,3 kW
Demand cost: 324 R/kW per year
Energy cost: 0,05 R/kWh
Net discount rate: 8 % per year
Normal max. loading (p.u.): 0,8

C.6.4.2 Analysis

The relative cash flow of the more expensive installation is illustrated in table C.3.

Table C.3 — Relative cash flow of the more expensive installation

<table>
<thead>
<tr>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Financial parameter used</td>
<td>Year 0 R</td>
<td>Year 1 R</td>
<td>Year 2 R</td>
<td>Year 3 R</td>
</tr>
<tr>
<td></td>
<td>Investment</td>
<td>-14 560</td>
<td>1 815</td>
<td>1 815</td>
<td>1 815</td>
</tr>
<tr>
<td></td>
<td>Saving in losses at full load</td>
<td>0</td>
<td>1 815</td>
<td>1 815</td>
<td>1 815</td>
</tr>
<tr>
<td></td>
<td>Saving not realized</td>
<td>0</td>
<td>-1 362</td>
<td>-907</td>
<td>-453</td>
</tr>
</tbody>
</table>

The NPV of the losses is the PV of the saving in losses at full load over 20 years minus the PV of the saving not realized during the early years. The PV of the annuity is:
Annex C  
(concluded)

\[
C_r \frac{r^n - 1}{r^n(r-1)} = 1815 \left( \frac{1.09^{20} - 1}{1.09^{20}(0.09)} \right) 
\]

\[= 1815 \times 9.128 \]

\[= 16568 \]

The PV of the saving not realized because of partial loading is:

\[-1362/1.09 - 907/1.09^2 - 453/1.09^3 \]

\[= -1250 - 763 - 350 \]

\[= -2363 \]

Therefore, the NPV of the whole investment model is:

\[-14560 + 16568 - 2363 = -355 \]

C.6.4.3 Conclusions

The financial model indicates that the lower losses of the more expensive installation are insufficient to justify the higher investment (the NPV is negative). If the system were fully loaded from the first year, the more expensive system would be advantageous (NPV = R2 008).

Sensitivity analysis assesses the effects of cost variations on the financial decision. For example, an increase of only 5% in the value of annual losses of R1 815 per year would change the NPV to a positive value and the more expensive network would be worthwhile.
Protection systems

D.1 Introduction

Ideally, the design of an LV system has to be such that the protective devices are co-ordinated with the complete system in the initial planning. Often in the past, designs have been based on load requirements and the protection was incidental. Due to the infrequency of operation, the lack of protection co-ordination might only become evident when it is too late.

The protection applied to cost-effective electrification schemes requires a balance between cost and performance. There are no cost-effective designs that are ideal. Instead, the most beneficial compromise between a number of options should be selected. This annex deals only with conductor thermal protection and overcurrent grading.

This annex describes an approach to low-voltage protection performance, gives information on the application of high rupturing capacity (HRC) fuses and circuit-breakers and gives examples of practical applications for the cost-effective protection of low consumption and moderate consumption areas.

D.2 An approach to LV protection performance (co-ordination)

D.2.1 Calculate the expected range of fault levels on the LV feeders.

D.2.2 Superimpose the appropriate protection curves on the same axes as the thermal limit (damage) curves of the transformer and LV feeders and of the service cable.

NOTE The thermal limit curves (damage curves) can be obtained from the manufacturers of the equipment.

D.2.3 Ensure that the protection elements will provide adequate protection over the expected range of fault levels.

D.2.4 Ensure that the protection is sensitive enough to respond to faults at the far end of the protection range.

D.2.5 It might be necessary to limit the length of LV distributors to ensure that fault levels will be high enough to operate the protection equipment.

D.3 High rupturing capacity (HRC) fuses and circuit-breakers

D.3.1 HRC fuses

D.3.1.1 Application of HRC fuses

SANS 60269-1 defines three utilization categories of fuses, i.e. gG, gM and aM. Class gG fuses are suitable for the protection of LV distribution networks. Class gL fuses of VDE 0636-301 have the same utilization class as gG of SANS 60269-1 and are therefore also suitable for the protection of LV distribution networks.
D.3.1.2 Selection of HRC fuse rating

The inherent overload capability of class gG fuses (see SANS 60269-1) has to be taken into account when a fuse rating is being selected for a particular application. Two current levels are defined by SANS 60269-1, as follows:

a) conventional non-fusing current \( (I_{nf}) \): a value of current specified as that which the fuse-link is capable of carrying for a specified time (conventional time) without melting; and

b) conventional fusing current \( (I_f) \): a value of current specified as that which causes operation of the fuse-link within a specified time (conventional time).

Table D.1, which has been extracted from SANS 60269-1, gives the overload capability of class gG fuses.

Table D.1 – Conventional times and currents for class gG fuses

<table>
<thead>
<tr>
<th>Rated current ( I_n ) for class gG fuses A</th>
<th>Conventional time h</th>
<th>Conventional non-fusing current ( I_{nf} )</th>
<th>Conventional fusing current ( I_f )</th>
</tr>
</thead>
<tbody>
<tr>
<td>( I_n &lt; 16 )</td>
<td>1</td>
<td>1,25 ( I_n )</td>
<td>1,6 ( I_n )</td>
</tr>
<tr>
<td>( 16 \leq I_n &lt; 63 )</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>( 63 \leq I_n &lt; 160 )</td>
<td>2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>( 160 \leq I_n &lt; 400 )</td>
<td>3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>( 400 \leq I_n )</td>
<td>4</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table D.1 implies that class gG fuses rated at \( 63 \text{ A} \leq I_n < 160 \text{ A} \) will allow a current of \( 1,25 I_n \) to flow for 2 h without melting. A current of \( 1,6 I_n \), however, will melt the fuses within 2 h.

D.3.1.3 Advantages and disadvantages of HRC fuses

D.3.1.3.1 The advantages of HRC fuses are:

a) very fast operation at high currents enables current limiting and the reduction of electromagnetic stress on connected plant;

b) discrimination of upstream and downstream fuses for large currents is possible, if fuses are selected properly;

c) they are static devices suitable for application in unfriendly environments, for example high humidity; and

d) they can be used with convenient fuse carriers that allow operation from ground level.

D.3.1.3.2 The disadvantages of HRC fuses are:

a) they are single-phase devices. In the event of the operation of one fuse on a three-phase system it is recommended that all three fuses be replaced;
b) fuses that have operated are often replaced with an incorrectly rated fuse, leading to protection maloperation; and

c) consumers with a three-phase supply might be reduced to a supply with only one or two phases.

D.3.2 Circuit-breakers

D.3.2.1 Application of circuit-breakers

The tripping characteristics of a low-voltage circuit-breaker can generally be divided into two parts, i.e. overload and short-circuit operation. Overload operation is achieved by introducing a time delay, either through a thermal device or through a hydraulically controlled mechanism within the circuit-breaker. Short-circuit operation is magnetically controlled and of fixed duration. When thermal magnetic circuit-breakers are used, their full-load rating is specified at an operating temperature, usually 65 °C. Thermal devices are temperature sensitive. Tripping current settings have to be corrected if the ambient temperature is greater than the temperature specified by the manufacturer at rated value. If necessary, electronic trip units can be used that are not influenced by temperature fluctuations. However, the maximum permissible circuit-breaker current is dependent on temperature and the trip settings might have to be limited.

D.3.2.2 Selection of circuit-breaker rating

LV circuit-breakers should comply with SANS 156, time-delay type, or with SANS 60947-2, category B type.

D.3.2.3 Advantages and disadvantages of the use of circuit-breakers

D.3.2.3.1 The advantages of circuit-breakers are:

a) they can be reset after operation; and

b) all three phases are tripped for a single-phase fault.

D.3.2.3.2 The disadvantages of circuit-breakers are:

a) for large fault currents, total discrimination might not be possible; the manufacturer's $I^2t$ versus $I$ and $t$ versus $I$ curves should be consulted;

b) they require an additional enclosure; and

c) they are not easily operated from ground level.

D.4 Preferred practical applications for cost-effective protection of low consumption and moderate consumption areas

D.4.1 General

For cost-effective electrification schemes, the protection functions of some of the classic protection elements shown in figure 6 (see 4.7.1) are combined or even removed. It is important for the designer to take cognizance of the protection and operational implications of these options. D.4.2 and D.4.3 cover the options that are most popular in practice.
D.4.2 Using a completely self-protecting (CSP) transformer

NOTE   CSP options are given in SANS 780.

Figure D.1 shows the layout when a CSP transformer is used.

![Diagram of CSP transformer layout](image)

**Figure D.1 — Using a CSP transformer**

D.4.3 Using a conventional transformer that complies with SANS 780

Figures D.2 and D.3 show the two preferred options when conventional transformers are used.

![Diagram of conventional transformer layout with one external fuse per phase](image)

**Figure D.2 — Using a conventional transformer with one external fuse per phase**

![Diagram of conventional transformer layout with two external fuses per phase](image)

**Figure D.3 — Using a conventional transformer with two external fuses per phase**
D.4.4 Cost and operational comparison of the cost-effective options

D.4.4.1 Options

Three basic protection options are given in D.4.2 and D.4.3. In practice, these protection options can be implemented as follows:

a) a CSP 100 kVA or 200 kVA transformer with a 120 A pole-top circuit-breaker for every four service connections;

b) a conventional 100 kVA transformer with MV drop-out fuse links, one 160 A LV pole-top fuse unit and one 120 A pole-top circuit-breaker for every four service connections; and

c) a conventional 100 kVA transformer with MV drop-out fuse links, two 125 A LV pole-top fuse units and one 120 A pole-top circuit-breaker for every four service connections or a 200 kVA transformer with MV drop-out fuse links, two 160 A LV pole-top fuse units and one 120 A pole-top circuit-breaker for every four service connections.

D.4.4.2 Costs

The cost of the transformer and the cost of associated protection hardware for the options given in D.4.4.1 (a), (b) and (c) are compared in table D.2. The comparison is based on the cost of the following materials and excludes labour costs and the costs of pole hardware:

a) the transformer;

b) drop-out fuse links, if used;

c) LV fuses, if used; and

d) the LV fuse carrier, if used.

NOTE For the sake of comparison, options D.4.4.1(b) and D.4.4.1(c), without the inclusion of the MV drop-out fuse links, are included as options D.4.4.1(d) and D.4.4.1(e).

D.4.4.3 Comparison

The overload capability of the transformer is determined by dividing the total cost of the components by the number of consumers that can be supplied from the transformer. The comparison is based on 100 kVA and 200 kVA transformers used at an ADMD of 0,6 kVA and 2 kVA per stand. Option (a) has been allocated a per-unit cost of 1.
Annex D

(continued)

Table D.2 — Relative cost comparison of protection options

<table>
<thead>
<tr>
<th>Option (see D.4.4.1 and the NOTE to D.4.4.2)</th>
<th>Per-unit cost of components</th>
<th>100 kVA transformer</th>
<th>200 kVA transformer</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0,6 kVA per stand</td>
<td>2 kVA per stand</td>
<td>0,6 kVA per stand</td>
</tr>
<tr>
<td>(a)</td>
<td>1,00</td>
<td>1,00</td>
<td>1,00</td>
</tr>
<tr>
<td>(b)</td>
<td>1,30</td>
<td>1,31</td>
<td>N/A</td>
</tr>
<tr>
<td>(c)</td>
<td>1,38</td>
<td>1,40</td>
<td>1,20</td>
</tr>
<tr>
<td>(d)</td>
<td>1,23</td>
<td>1,24</td>
<td>N/A</td>
</tr>
<tr>
<td>(e)</td>
<td>1,31</td>
<td>1,33</td>
<td>1,16</td>
</tr>
</tbody>
</table>

NOTE The unit costs are based on the cost of the transformer and the cost of associated protection hardware in 1996. Although the actual costs of these items might change, it can be expected that the per-unit costs will remain relatively stable. However, the user is advised to verify actual costs before committing to a particular option.

D.4.4.4 Advantages and disadvantages of option (a) in table D.2

D.4.4.4.1 The advantages of option (a) in table D.2 are:

a) it has the lowest material costs;
b) it has no protection discrimination problems;
c) it is of simple construction – MV and LV protection are inside the transformer;
d) it has a larger number of consumers connected for each transformer;
e) it provides 100 % transformer overload protection; and
f) it provides good feeder protection, provided that the LV distributor length is limited.

D.4.4.4.2 The disadvantages of option (a) in table D.2 are:

a) it is applied with limited sectionalizing capabilities on the MV. Typically, five transformers will be used for each off-load section point;
b) it has the possibility of internal MV fuse failure, due to incoming surges; however, very few of these incidents have been reported;
c) it allows limited MV sectionalizing, since there is no visible point of isolation of the MV at the point of work;
d) it has no visible isolation with the LV breaker in the "open" position;
e) it has only one point of isolation for the entire LV distributor network; and
f) it has limited quality of supply.

D.4.4.5 Advantages and disadvantages of option (b) in table D.2

D.4.4.5.1 The advantages of option (b) in table D.2 are:
Annex D
(continued)

a) it gives improved feeder protection compared with option (a) in table D.2. The practical restriction imposed on feeder length by voltage drop limitations will be sufficient to prevent unacceptably low fault currents;

b) it has an MV point of isolation at each transformer which will enable a better quality of supply when compared with option (a) in table D.2; and

c) it has a visible point of isolation with the LV fuses open.

D.4.4.5.2 The disadvantages of option (b) in table D.2 are:

a) it shows a 20 % to 30 % increase in transformer and associated protection hardware costs, when compared with option (a) in table D.2;

b) it is of more complicated construction when compared with option (a) and requires external MV and LV fuse assemblies;

c) it has fewer consumers connected for each transformer than option (a) in table D.2;

d) it provides limited overload protection of the 100 kVA and 200 kVA transformers;

e) it could cause discrimination problems with the fuse and pole-top circuit-breaker on 100 kVA transformers; and

f) it has only one point of isolation for the entire LV distributor network and therefore quality of supply is limited.

D.4.4.6 Advantages and disadvantages of option (c) in table D.2

D.4.4.6.1 The advantages of option (c) in table D.2 are:

a) it has an MV point of isolation at each transformer, which will enable a better quality of supply when compared with option (a) in table D.2;

b) it has a visible point of isolation with the LV fuses open;

c) it has two points of isolation for the LV distributor network, which will enable a better quality of supply when compared with options (a) and (b) in table D.2; and

d) it provides 100 % protection of the feeders.

D.4.4.6.2 The disadvantages of option (c) in table D.2 are:

a) it shows a 30 % to 40 % increase in transformer and associated protection hardware costs when compared with option (a) in table D.2;

b) it is of more complicated construction when compared with options (a) and (b) in table D.2 and requires external MV and two LV fuse assemblies;

c) it has fewer consumers connected to each transformer than option (a) in table D.2;

d) it provides no overload protection of the transformer; and

e) it could cause discrimination problems with the fuse and pole-top circuit-breaker on 100 kVA transformers that are more severe than those posed by option (b) in table D.2.
Bibliography

Introduction

This bibliography has been prepared for the benefit of electrical engineers involved in electrical planning and design and associated research in South Africa, and is based on a report by the Distribution Working Group of the Electric Power Co-ordinating Committee (EPCC).

The co-operation of the EPCC in the development of this bibliography is acknowledged. The Distribution Working Group of the Electric Power Co-ordinating Committee (EPCC-DWG) identified the need for a bibliography that would bring together the most important international references and the applicable papers that have been published in South Africa. The list has been sorted into the main subject groups appropriate to distribution engineering. A short introduction to each group identifies the most important concepts in the key references and indicates the scope of work covered by the papers in that clause.

The entries in each clause are arranged in chronological order. The content of some earlier documents might have been superseded by the content of more recent documents in the clause. The reader should therefore ensure that the latest available information is used.

References that appear as normative references in this part of NRS 034 are not included in the bibliography. The bibliography has been divided into the following clauses.

Load modelling and consumer characteristics

Load forecasting in distribution systems

Distribution system planning, analysis and design

  Introduction
  
  General subject matter
  
  Low-voltage systems
  
  Medium-voltage systems
  
  Power system analysis

Distribution system reliability and quality of supply

Distribution system economics

Overhead lines, cables, conductors and fittings

Distribution transformers and miniature substations

Low-voltage circuit-breakers and fuses

Earthing and earth leakage protection

Street lighting

Tariffs and metering
Load modelling and consumer characteristics

The way in which loads are modelled has a major impact on calculations of estimated voltage drop in LV networks that supply domestic consumers. Diversity and unbalance that arise from stochastic variation of the loads have to be taken into account.

Present load modelling programs used widely in South Africa use diversity and unbalance correction factors that are largely based on work done in the UK in the 1950s. More load measurement and analysis are required in this area to effectively characterize these loads and define simplified parameters for modelling loads in the Southern African context (this work is being co-ordinated through the NRS 034 Working Group).

The impact of demand-side management techniques will need to be included in load modelling although, for domestic consumers, this is generally limited to load shifting, water heating and air conditioning.

Several references by Herman, Gaunt and Dekena describe research undertaken in South Africa to establish equipment needs and the collection of load data for modelling domestic electrical loads. Gower describes an application of an ACE report to South African conditions. Anderson, Janson and Klevis, and Sarikas and Thacker attempt to relate maximum demand to annual energy usage.

Hamilton and Bary were two of the original researchers into load characteristics and are often quoted in later references. Rusck’s methods of representation of measured loads using coincidence factors based on a Gaussian statistical distribution were the basis of much work for the next two decades after publication in 1956. Willis, Vismor and Powell describe aspects of sampling load curve data using modern recording technology.


Covers a survey of the demand of groups of consumers.

BARY, C. *Coincidence factor relationships of electric load characteristics*. Transactions of the SAIEE, September 1945, vol. 64, p. 623.


Gives a representation of measured loads using coincidence factors based on a Gaussian statistical distribution.

SARIKAS, RH. and THACKER, HB. *Distribution system load characteristics and their use in planning and design*. Proceedings of the AIEE, August 1957, p. 564.

Attempts to relate maximum demand with energy usage using polynomial curve fitting. This is one of the early papers on load modelling and has been referred to by authors such as Gönen.

DAVIS, MW., KRUPA, TJ. and DIEDZIC, MJ. *The economics of direct control of residential loads on the design and operation of the distribution system*. IEEE (Transactions on Power Apparatus and Systems), March 1983, vol. PAS-102, no. 3, p. 646.

Defines load management terms, develops a new approach for evaluating the cost-effectiveness of control strategies and reports how a field experiment implemented on a distribution circuit was designed to measure the effects of a utility load management programme.
Bibliography
(continued)


Discusses aspects of sample rate, filtering and digital sampling.

GOWER, AH. A statistical approach to the determination of consumer design ADMDs using average annual energy consumption figures. SAIEE (Workshop on: Towards cost-effective power distribution and reticulation), August 1987.

Applies the principles of the British ACE Report 49 to South African conditions.


Describes a load forecasting model based on recorded daily demand curves. The data are collected using a measuring and memory device attached to the energy meters.

HARDING, IL. and HOCHSTEIN, B. An integrated information management system for distribution networks. CIRED (Tenth International Conference on Electricity Distribution), Brighton, 1989, p. 373.


Covers a research project undertaken to establish equipment needs and methodology for collecting electrical load data and for modelling electrical loads in South Africa.


Includes further work on the analysis of collected data (see the previous reference), particularly the effect of constraints, for example, tariff circuit-breakers.


Shows that the Beta probability density function is most appropriate for the parametric, statistical description of domestic loads at the time of maximum demand.


Based on a doctoral dissertation on voltage regulation calculation, this paper presents a probabilistic method of calculating voltage drops based on the Beta probability density function. The method has subsequently been named the Herman-Beta method.


Describes work carried out in and results from the NRS Load Research Project.


Examines a variety of current South African voltage drop calculation methods using carefully selected benchmark networks and loads. The results are compared with Monte-Carlo simulations. The conclusions are that the Herman-Beta method is the most reliable.


### Load forecasting in distribution systems

Load forecasting has one of the biggest impacts on the phased capital investment requirement of distribution systems. As for load modelling, the effective categorizing of consumers’ loads in terms of the After Diversity Maximum Demand (ADMD) forecast levels and growth profile is very important.

The trend in distribution load forecasting is towards a geographically based methodology using geographic information system (GIS) technology.

Load forecasting falls into two classes, i.e. long-term and short-term forecasting. Long-term forecasting is generally used for design purposes. Huck and Mahmoud cover over 130 publications on forecasting up to 1981. Willis, Tram and Rackliffe deal with forecasting on a geographical basis and quote 108 references. Lee Lewis and Northcote-Green compare 14 distribution load forecasting methods.


Gives 74 references that deal with the general philosophy of load forecasting, including short notes on each paper.


Gives 62 references that concentrate on engineering economics, issues and parameters of load forecasting.


Deals with the forecasting of electric loads on a geographical basis. Gives a comprehensive review of techniques employed in spatial electric load forecasting (108 references).


Evaluates the methods on the basis of usefulness as a planning tool, and deals with forecast accuracy and cost of application.

Bibliography (continued)


Describes a new method of extrapolating feeder peak load histories to produce estimates of future peak load histories.

Distribution system planning, analysis and design

Introduction

This area covers a wide range of issues to optimize the configuration and investment made in distribution systems so as to comply with consumers' load requirements within acceptable quality of supply limits with the lowest net present value cost. The references under E.4 have been subdivided for ease of reference.

Consumers' quality of supply requirements will probably lead to negotiations between suppliers and major consumer representatives to determine the expected levels of service and the associated capital and running costs that will be reflected in the tariffs.

References relating to design procedures in South Africa are by Gaunt, Ben-Dov, Harley and Seymore, Swanepoel and Dekena. The two IEEE papers, by Gönen and Mahmoud, and Gönen and Ramires-Rosado, are excellent bibliographies of power system planning and distribution in the USA. The paper by Davies and Paterson is a classical work on calculating voltage drop using a statistical description of the stochastic domestic loads. Walkden uses the methods of Davies and Paterson to derive a procedure for the selection of optimum cable sizes. Brodsky, Wrobel and Willis consider different voltage modelling methods in load flow calculations. Wepener and Gaunt describe the choice between 11 kV and 22 kV for distribution voltage.

General subject matter


Reviews the aims and experiences of the London Electricity Board in standardizing all major items of plant and equipment used in the supply of electricity at voltages ranging from 66 kV to 240 V, including switchgear, transformers, underground-link disconnection boxes and fusible cut-outs.

SANS 10121 (SABS 0121), Cathodic protection of buried and submerged structures.


Lists 72 papers under the headings analysis, models and techniques.

SANS 10313, The protection of structures against lightning.

GAUNT, CT. Implications of planning and design decisions in electricity distribution. Twelfth AMEU technical meeting, Potchefstroom, September 1988.

Bibliography
(continued)


Discusses the factors which affected the evolution of the world’s distribution systems, and their divergence, with implications for application in lesser developed countries.

Distribution Technology Division, Eskom. *Distribution standard*.

A compilation of practices, available from the Distribution Technology Manager, Private Bag X1074, Germiston, 1400.


A comprehensive book with an American bias.

**Low-voltage systems**


Describes the design and performance of the distribution system of Welkom.


A particularly rigorous mathematical analysis of a statistical approach to voltage calculations in unbalanced low-voltage cables.


Describes a procedure for selecting cables for radially connected low-voltage networks so that the volume of the conductor is minimized. Includes voltage regulation and currents ratings (four references).


Presents an algorithm for the optimal placement of transformers and substations and the sizing of cables.


Outlines the development of calculation factors for voltage drop in low-voltage radial feeders.
Bibliography
(continued)


Describes a method of simulating feeder performance based on coincident probability distribution of demand at system peak, based on loss-of-diversity and unbalanced voltage drop factors.

Durban Electricity. *Durban Electricity planning code of practice*.

Gives procedures for planning electrical distribution.

Medium-voltage systems


Gives the selection of the medium-voltage level for industrial township distribution.


Presents the results of the Fuse Performance and Application Revaluation (FUSEPAR) Programme.

Power system analysis

This topic covers the analytical methods and mathematical theory that are used for the analysis of load flow and voltage regulation of the distribution power systems and to analyse the response of those systems to short-circuits following faults on the network.

The majority of the references in this section are books that deal with a variety of topics in power system engineering. The texts by Stevenson, Elgerd, Moorhouse and Gross are of a general nature and cover the broad spectrum of power systems aspects. The texts by Gönen, Lackervi and Holmes, and the Westinghouse Electricity Corporation’s reference book concentrate on distribution systems. The somewhat dated, yet useful book by Starr, deals with electricity utilization. Seidman and Mahrous deal with classical solution methods for hand calculations.


Covers generation, transmission, overhead lines (mechanical and electrical design), underground cables, voltage regulation stability, switchgear and protection, illumination, electric traction and industrial utilization.

Presents the more important problems of power system analysis. Deals with three-phase faults on synchronous machines, asymmetrical faults, power system stability and economic operation.


Presents a general approach, using simple matrix methods, and brings together several system and machine topics which are often treated separately.


Covers power system components and overall system behaviour, and also automatic closed loop control of generators, optimum operation, load flow analysis and emergency control.


Reviews the nature of short-circuits to aid in the understanding of standard US requirements. Covers short-circuit, series connection, protection device and power fault systems.


Introduces time functions of short-circuit currents close to and remote from the generator and deals with calculations based on symmetrical components and the evaluation of short-circuit impedances. Indicates the possibilities of determining short-circuit currents with the aid of digital computers.


Discusses the multistage planning model and allows for constraints of radiality and voltage drops in a mixed integer programming framework (25 references).


Serves as an introductory course to power system analysis.


Focuses on how different modelling methods incorporated into three-phase power flow analyses affect computed results. Highlights theory of distribution design and some fundamental shortcomings in existing design guidelines, including the effect of circuit-breaker restriction on maximum demand.

MIRANDA, V. and MATOS MACC. *Distribution system planning with fuzzy models and techniques*. CIRED (Tenth International Conference on Electricity Distribution), 1989, p. 472.

Describes tests to determine the impulse characteristics of the secondary system of a residential service.


Describes how a distribution system designer would use computer software with a graphical user interface to route and select cables in a new scheme.


Merlin Gerin. *Calculation of short-circuit currents*. Cahiers techniques No. 158. (Available from Schneider, Service Commercial et Technique. F 38050 Grenoble Cedex 09 (Fax 76419860).)


**Distribution system reliability and quality of supply**

Reliability analysis in electrical power engineering is mostly applied to generation and transmission planning. Application at the distribution level is not as well described. Gilligan, Settembrini, Fisher and Hudak consider the reliability of distribution systems and Marinello distinguishes between momentary and permanent outages. The other authors address the reliability of particular components.


Examines the distortion effects of fluorescent lighting loads on the supply waveform.

MAY, HS. *The design of overhead electric lines for improved reliability*. CIRED (Tenth International Conference on Electricity Distribution), Brighton, 1989, p. 196.


Describes how the expected reliability performance of primary distribution circuits can be estimated by a direct assessment of the configuration and exposure of the circuit.

Shows how failure rates of underground distribution system components can be determined from historical data.


Describes a study of a number of rural and urban overhead distribution feeders to develop generic service time failure rates for seven overhead component types.


Studies the effect of converting momentary outages to permanent outages on distribution feeders and the relationship of momentary outages to good power quality.


Examines the design and operating parameters of seven common distribution systems and compares the performance of each in terms of reliability and power quality.


Discusses various protective schemes against out-of-phase reclosing and transfer, and riding through voltage dips.


Describes the calculation of the quantity and locations of voltage-correcting capacitors on distribution lines using two different computer models.


NRS 048-2, *Electricity supply – Quality of supply – Part 2: Voltage characteristics, compatibility levels, limits and assessment methods*.


NRS 034-1:2007
Distribution system economics

Engineering economics, as treated in the following references, mostly refers to the financial implication of choosing between alternative actions. Grainger and Kendrew, and Hickok address the cost of distribution losses in the system in general, and Nickel and Braunstein, the cost of losses in transformers. Hass and Gustafson, Kirshner and Giorsetto, and Steese, Merrick and Kennedy assess the changes in costs of losses through system management. Taylor and Boal give a good general description of the wider economic analysis of power systems and Palser describes the formulas used in financial analysis.


HICKOK, HN. *Electrical energy losses in a power system*. IEEE (Transactions on Industrial Applications), October 1978, vol. 1A-14, no. 5, p. 373.

Provides typical loss data on electrical equipment and discusses measurement problems. Examines system design criteria for reducing losses.


Explores the application of a distribution loss model that has been designed to discretely measure resistance, no-load and reactive losses for a given system and mode of operation.


Examines methods for the evaluation of distribution transformer loss. The total levelized annual cost method is extended to properly account for conditions of energy cost inflation, load growth and transformer changeout.


Serves as an introduction to engineering economics. Considers the basic principles of compounding and discounting and the application of these principles to the various discounted cash flow methods of investment appraisal.


Focuses on the energy savings that can be achieved by conservative voltage reduction.


Focuses on the energy savings that can be achieved by conservative voltage reduction.

IEC 60287-3-2, *Electric cables – Calculation of the current rating – Part 3: Sections on operating conditions – Section 2: Economic optimization of power cable size*. 
Overhead lines, cables, conductors and fittings

Many books and papers have been published on the general design and installation of overhead lines and cables. This subclause of the bibliography identifies fourteen South African codes of practice, and relevant specifications. Clarke and Scott, and Coney describe particular aspects of aerial bundled conductors that are commonly used in South Africa.


Contains formulas, graphs, tables, explanations of theoretical relationships and numerous definitions.

BS 16, *Specification for telegraph material (insulators, pole fittings, etc.)*.

SANS 1294, *Precast concrete manhole sections and components*.


Describes general features of various kinds of cable.

SANS 1411-1 (SABS 1411-1), *Materials of insulated electric cables and flexible cords – Part 1: Conductors*.

SANS 1411-2, *Materials of insulated electric cables and flexible cords – Part 2: Polyvinyl chloride (PVC)*.

SANS 1411-4, *Materials of insulated electric cables and flexible cords – Part 4: Cross-linked polyethylene (XLPE)*.

SANS 1411-6 (SABS 1411-6), *Materials of insulated electric cables and flexible cords – Part 6: Armour*.

CONELY, R. *Application and protection of aerial bundled conductors*. Eskom, SAIEE (Workshop on: Towards cost-effective power distribution and reticulation), August 1987.


Compares various aspects of the two types of cable.

SANS 10198-1, *The selection, handling and installation of electric power cables of rating not exceeding 33 kV – Part 1: Definitions and statutory requirements*.

SANS 10198-2, *The selection, handling and installation of electric power cables of rating not exceeding 33 kV – Part 2: Selection of cable type and methods of installation*.

SANS 10198-4, *The selection, handling and installation of electric power cables of rating not exceeding 33 kV – Part 4: Current ratings*.

SANS 10198-6, *The selection, handling and installation of electric power cables of rating not exceeding 33 kV – Part 6: Transportation and storage*. 
Bibliography (continued)

SANS 10198-7, The selection, handling and installation of electric power cables of rating not exceeding 33 kV – Part 7: Safety precautions.

SANS 10198-8 The selection, handling and installation of electric power cables of rating not exceeding 33 kV – Part 8: Cable laying and installation.

SANS 10198-9 (SABS 10198-9), The selection, handling and installation of electric power cables of rating not exceeding 33 kV – Part 9: Jointing and termination of extruded solid dielectric-insulated cables up to 3,3 kV.

SANS 10198-10 (SABS 10198-10), The selection, handling and installation of electric power cables of rating not exceeding 33 kV – Part 10: Jointing and termination of paper-insulated cables.

SANS 10198-11 (SABS 10198-11), The selection, handling and installation of electric power cables of rating not exceeding 33 kV – Part 11: Jointing and termination of screened polymeric-insulated cables.

SANS 10198-13 (SABS 10198-13), The selection, handling and installation of electric power cables of rating not exceeding 33 kV – Part 13: Testing, commissioning and fault location.

SANS 10198-14 (SABS 10198-14), The selection, handling and installation of electric power cables of rating not exceeding 33 kV – Part 14: Installation of aerial bundled conductor (ABC) cables.


SANS 1507, Electric cables with extruded solid dielectric insulation for fixed installations (300/500 V to 1 900/3 300 V). All parts.

SANS 1411-3, Materials of insulated electric cables and flexible cords – Part 3: Elastomers.


SAUNDERS, RH., MEAL, DV., GELDENHUYS, HJ. et al. Covered conductors: Insulation co-ordination and material considerations based on a battery of tests. ENER-C 90991, January 1990.

SANS 60383-1/IEC 60383-1 (SABS 60383-1), Insulators for overhead lines with a nominal voltage above 1 000 V – Part 1: Ceramic or glass insulator units for a.c. systems – Definitions, test methods and acceptance criteria.

SANS 60720/IEC 60720 (SABS IEC 60720), Characteristics of line post insulators.

BS 65, Specification for vitrified clay pipes, fittings and ducts, also flexible mechanical joints for use solely with surface water pipes and fittings.

NRS 020, Electricity distribution – Cable ties for use with low-voltage aerial bundled conductors.


Provides a better understanding of the variables that produce cable-pulling tension, and explains how better estimates of tension can be made possible.

Discusses the key selection criteria for power, control and communication cables when used in transmission and distribution facilities.

SANS 470, Concrete poles for telephone, power and lighting purposes.

NRS 032, Electricity distribution – Service distribution boxes: Pole-mounted types – For overhead single-phase a.c. service connections at 230 V.

SANS 753, Pine poles, cross-arms and spacers for power distribution, telephone systems and street lighting.

SANS 754, Eucalyptus poles, cross-arms and spacers for power distribution and telephone systems.

SANS 10280 (SABS 0280), Overhead power lines for conditions prevailing in South Africa.

NRS 018-1, Fittings and connectors for low-voltage overhead power lines using aerial bundled conductors – Part 1: Strain and suspension fittings for self-supporting conductors.

NRS 018-2, Fittings and connectors for low-voltage overhead power lines using aerial bundled conductors – Part 2: Strain and suspension fittings for insulated neutral supporting conductors.

NRS 018-3, Fittings and connectors for low-voltage overhead power lines using aerial bundled conductors – Part 3: Strain and suspension fittings for bare neutral supporting conductors.

NRS 018-4, Fittings and connectors for low-voltage overhead power lines using aerial bundled conductors – Part 4: Strain and suspension fittings for aerial service cables.

NRS 018-5, Fittings and connectors for low-voltage overhead power lines using aerial bundled conductors – Part 5: Current-carrying connectors and joints.

NRS 022, Electricity distribution – Stays and associated components.

Durban Electricity, Durban Electricity overhead lines code of practice.

Gives procedures for erecting overhead lines and associated work.

Durban Electricity, Durban Electricity underground cables code of practice.

Gives procedures for laying and jointing underground cables and associated work.

CLARKE, EG. and SCOTT, ED. Coupling between aerial bundled conductors and telephone cables on the same pole. Eskom, Engineering Investigations Report, TRR/E89/T008, Johannesburg.

Describes tests to determine electrostatic and electromagnetic induction between MV and LV ABCs and a telephone cable accommodated on the same wooden poles. Psophometric voltages are also measured.
Distribution transformers and miniature substations

Transformers play an essential role in the distribution system. For network planning and design, the transformers are usually considered as a simple black box. Norman addresses the standardization of transformer parameters from a system viewpoint. The IEEE standard describes how cyclic loading influences the effective rating of a transformer. The code of practice describes operating and maintenance aspects.


For the majority of its future applications, Eskom intends to specify standard values for the main electrical parameters of its system transformers. This paper gives details of the proposed values for these standard parameters and outlines some of the principle reasons for their selection.

SANS 1029, Miniature substations.

SANS 1037 (SABS 1037), Standard transformer bushings.

SANS 1473-1, Low-voltage switchgear and controlgear assemblies – Part 1: Type-tested, partially type-tested and specially tested assemblies with rated short-circuit withstand strength above 10 kA.


SANS 60439-1/IEC 60439-1, Low-voltage switchgear and controlgear assemblies – Part 1: Type-tested and partially type-tested assemblies.


Proposes a new evaluation method that will provide the user with a distribution transformer design that has a lower operating temperature rise thus improving both the transformer’s efficiency and the consumer’s total owning cost.


Reviews the application of an individual current-limiting fuse on pole type distribution transformers.


Looks at influences on transformer enclosure design, especially influences related to product integrity.


Discusses the development of an internally mounted low-voltage spark gap as a protection device. Transformer tests and field trials of the prototype have demonstrated its effectiveness.

Discusses a distribution transformer modelling procedure that represents the distribution transformer with a minimum of input data for network, load and fault studies thereby allowing the transformer to be routinely included as part of the distribution network.


Describes a method for state space formulation of machine windings.


Details experiments that were carried out to determine the hottest spot temperature allowance for a cast-resin dry type transformer. The locations of the hottest spot for the primary and secondary winding were determined.


Describes a method for determining the correct economic size of distribution transformers using end-use appliance load profiles and the thermal model in ANSI/IEEE standard C57.91:1981.

IEEE standard C57.91:1995, Cyclic loading of transformers in urban dormitory areas.

Durban Electricity, Durban Electricity substations code of practice.

Gives procedures for the commissioning and maintenance of equipment in substations and associated work.

**Low-voltage circuit-breakers and fuses**

The need for moulded-case circuit-breakers was created in the period leading up to 1920, when numerous new applications for electrical motors resulted in a demand for a device that would ensure safe operation and, at the same time, protect the electrical circuits. During this period, individual motors were used for the first time in industrial plants to operate machine tools and in private homes to operate appliances such as refrigerators and washing machines. These numerous applications created problems. Plant electricians were constantly changing fuses that had been blown during motor start-up. The same problem of replacing blown fuses occurred in homes when circuits were overloaded. Inspectors were concerned about fire hazards because fuses were being bridged with coins and hairpins or fuses with higher current ratings were being installed.

The work of manufacturers prepared the ground for the eventual development of the compact moulded-case circuit-breaker, which was introduced by the Westinghouse Electric Corporation in 1927. Technology developments in recent decades have been significant.

This subclause of the bibliography lists several references to applications of moulded-case circuit-breakers and identifies the more important national and international standards applicable to these devices.
Bibliography
(continued)

SANS 156, *Moulded-case circuit-breakers*.


Examines the design, operation, standards and ratings of current limiting moulded-case circuit-breakers in relation to earlier fused applications.


A protection guide that gives the fundamentals of low-voltage protection and methods of calculating short-circuit currents.


Investigates the requirements for the testing of current circuit-breakers, particularly when applied in a series-connected arrangement.


Reviews the nature of short-circuits to aid in an understanding of standard US requirements.


Examines selective co-ordination in electric distribution systems in relation to current limiting and cascading systems.


Examines the requirements for moulded-case circuit-breakers and relates them to the differences in test methods between South African, USA and IEC standards.


Discusses the differences in standards governing the proper use of a circuit-breaker relative to short-circuit and momentary ratings. Reviews the ratings of indoor oil-less circuit-breakers.


Analyses the misconceptions of current limiting in low-voltage circuit protection and gives recommendations for effective “cascaded” protection.
Bibliography


Analyses the requirements for specifying moulded-case circuit-breakers with particular reference to the protection of induction motors under direct-on-line starting conditions and gives recommendations.


Compares SANS 156 and IEC 60947-2 and gives recommendations for harmonization.


Covers the development of a computer program that performs cable design and selection functions and then selects the correct moulded-case circuit-breaker to protect that cable.


Earthing and earth leakage protection

The question regarding the possibility of the dangers of electric current to human beings was raised by experimenters who, in the eighteenth century, had already carried out tests with electrostatic machines. Serious research on the physiological effects of electric current on living systems followed after the first fatal electrical accidents had become known during the second half of the nineteenth century. It was, however, not until the 1930s that clear goals were set in Germany for the development of a successful technique for taking protective measures against electrical accidents.

The first extensive measurement of fibrillation thresholds in animals were carried out by an American team in 1936. Growing interest in the subject resulted in much work being done in both the USA and Austria during the 1950s, which was continued through the 1970s. This work contributed to our understanding today of the effects of electric current on the human body.

The earliest forms of voltage-operated earth leakage relays, which were developed in the UK in the 1930s, have long since been discarded and replaced by current-sensing devices. The foundations for earth leakage protection were to a large extent created in the South African underground mining industry, where the need for protection against fatal shock hazards on the 525 V a.c. distribution system was soon recognized. This resulted, in 1957, in South Africa’s developing the world’s first people-protection device, soon followed by the publication of SABS 767, which was the world’s first product standard covering earth leakage protection units.

In the next three decades, the importance of earth leakage protection circuit-breakers as the ideal mechanism for protection against electrical shock and fire hazards was recognized internationally.

The following bibliography presents only a brief listing of references that are applicable to earth leakage protection and to the effects of electric current on the human body.

MIDDLECOTE, AA. Earth leakage. AMEU (Thirty-first Convention), Margate, May 1957.

Comprises an examination into earthing conditions in South Africa related to accidents and the conclusion that current-operated earth leakage protection is needed.


Comprises an examination into standard requirements for current-operated earth leakage circuit-breakers and the tendencies towards greater sensitivity.


Gives a detailed analysis of the effects of low frequency electric currents on the human body.


Analyses the effects of electric currents on the human body, relating it to the establishment of a maximum tripping current for earth leakage circuit-breakers in British standards.


Examines the effects of electric currents on the human body in relation to practical aspects of sensitive earth leakage protection in South Africa.


Summarizes the studies that determined the effective human body impedance under varying conditions and the protective devices available.

ADAMS, KAH. Protection systems – hazards of shock in mines. SAIEE Transactions, April 1975.

Examines earthing conditions and requirements in South African underground mines and the related hazards of earth faults.

CASTENSCHIOLD, P. Combining GFP and emergency power systems. ECM Magazine, December 1976.

Examines ground fault protection applied to emergency power systems, while maintaining overall electrical system reliability.


Examines the effects of double grounding faults on sensitive earth leakage protection devices, with special reference to grounded systems.
Bibliography
(continued)


A protection guide that gives the fundamentals of low-voltage protection using moulded-case circuit-breakers and earth leakage circuit-breakers.

IEC 60755, General requirements for residual current-operated protective devices.

SANS 10200 (SABS 0200), Neutral earthing in medium voltage industrial power systems.

SANS 1063 (SABS 1063), Earth rods and couplers


Reviews the history of body impedance studies and correlates it to earlier work.


Analyses current transformers and relaying systems that cover the concepts behind sensitive ground fault relaying for use on low-voltage utilization systems.

SANS 61008-1/IEC 61008-1, Residual current operated circuit-breakers without integral overcurrent protection for household and similar uses (RCCBs) – Part 1: General rules.

Gives standard IEC requirements for residual current-operated circuit-breakers without overload protection.


Indicates important protection principles and their applications.


Analyses the principles of earth leakage protection devices and the effects of earth fault currents on humans.

IEC 60364-4-41, Electrical installations of buildings – Part 4-41: Protection for safety – Protection against electric shock.


Covers an interview regarding the use of earth leakage protection in homes.

IEC 61009-1, Residual current operated circuit-breakers with integral overcurrent protection for household and similar uses (RCBOs) – Part 1: General rules.


Covers the historical development of earth leakage protection, with particular reference to the South African contribution. Indicates the potential cost savings from relaxation of regulatory requirements in an environment that requires good shock and fire hazard protection.

Summarizes the effects of electric currents passing through the human body in relation to the electrical impedance of the human body.

SANS 10292 (SABS 0292), *Earthing of low voltage (LV) distribution systems.*

**Street lighting**


SANS 1459, *Traffic lights.*

SANS 1777, *Photoelectric control units for lighting (PECUs).*

**Tariffs and metering**

The most common method of collecting revenue for electricity sales is the “credit” method. This system is well established and operates successfully, from the point of view of both the supply authority and the consumer. The metering equipment required is inexpensive, long lasting, reliable and accurate and the accounting system can be similarly uncomplicated and economical.

There are circumstances, however, where the credit system is unlikely to succeed because of environmental, social and institutional factors, particularly in developing communities.

In circumstances where the credit system is likely to fail, or where the consumption is small or inconsistent, some form of pre-payment system might provide an appropriate alternative.

HORLENT, A. *New metering and reading techniques based on a modular design concept.* CIRED (Tenth International Conference on Electricity Distribution), Brighton, 1989, p. 455.


Describes the Digital Telewattmeter System (DTS) software package that provides both consumer-side load management and remote transmission of energy usage data for the utility.