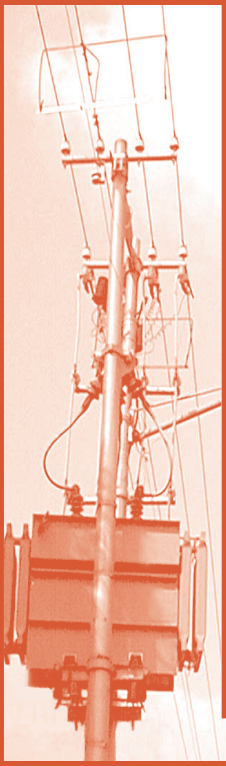
Grid electricity



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SCOPE

These guidelines cover aspects that need to be considered for the optimum planning and designing of electricity supply systems for residential townships, including developing communities.

INTRODUCTION

This section provides electricity layout planners with the required background to effectively follow the correct steps to achieve optimal design. It describes the approach to "greenfield" projects with reference to the information, resources and documentation available to assist the planner/designer. Original content is kept to a minimum and there is effective referencing to established documents with explanatory notes where necessary. The guidelines are written with low technical content to maximise ease of reading and practical application.

NOTE: Reference materials are continually being updated to match developments in technology.

The use of typical analytical software tools is described and substantiated with practical examples.

Special attention is given to the methods that can be used to estimate After Diversity Maximum Demand (ADMD) figures and the ADMD vs consumer classification relationships.

Details regarding the method that should be followed when optimising an electrical layout and technology selection are given. Practical tips on service connection strategies and recommendations on the voltage drop calculation method are given.

(See Appendix A for lists of reference documents).

PLANNING OVERVIEW

Role of planning

Planning is vitally important to ensure the optimal application of technology and to achieve the required quality of supply. Planners have to consolidate and validate the information received from marketing surveys. Using the information at hand, a selection of technology (voltages and ratings) and its application (layout and configuration of network) must be decided upon. A strong feedback system is required to ensure that the as-built status of the network is in accordance with the plan. The planner is responsible for ensuring that future upgrades are properly planned and optimised.

Experience has shown that it is best to plan the development of an area in phases. The area will have an initial plan and a future envisaged masterplan. The implementation of the masterplan in phases is known as a "phased implementation plan". The terms "master plan", "initial plan" and "phased implementation plan" are used in the text.

Initial plan

It is unlikely to be economically feasible to implement the master plan immediately, and an initial plan that caters for expected network loading after five to seven years must be implemented first. The objective is to delay capital expenditure for as long as possible to reduce life cycle costs, while maintaining an acceptable quality of supply.

Master plan

The master plan layout refers to the long-range plan for the area (based on the expected loading after 20 years), using the optimised technology. The objective of master planning is to ensure upgradability and optimised long-term infrastructure development.

TERMS AND DEFINITIONS

A glossary of terms used in the planning and design of electrical distribution systems is given in the National Rationalised Specifications NRS 034-Part 0. A few terms have been extracted and adapted for ease of reading in the context of this chapter. Definitions are listed below in alphabetical order.

After diversity maximum demand (ADMD)

The simultaneous maximum demand of a group of *homogeneous* consumers, divided by the number of consumers, normally expressed in kVA.

Thus the ADMD of N consumers is:

$$\text{ADMD (N)} = \frac{\text{MD(N)}}{\text{N}}$$

This value generally decreases to an approximately constant value for 1 000 or more consumers and has therefore been chosen as a convenient reference value. (Practically no difference in ADMD exists between 100 and 1 000 consumers.)

ADMD with no mention of the number of consumers (N) is defined as that representing the ADMD of 1 000 consumers, i.e.

$$\text{ADMD} = \text{ADMD(1 000)}$$

For customers who have the potential to have a high or very high demand, an individual customer's maximum demand is generally approximately two to three times the ADMD for a group of similar customers. For customers with a limited potential demand, in the very low, low, or moderate consumption range, an individual customer's consumption is typically four to five times the ADMD for a group of similar customers.

DSP

A domestic supply point (consumer metering point).

Intermediate voltage (IV)

An AC medium voltage in the range 1 000 V to 3 300 V phase-to-phase.

Intermediate voltage distribution

Typically a distribution system operating at a nominal AC voltage of 1,9 kV phase-to-neutral, or 3,3 kV phase-to-phase.

Load factor (LF)

A ratio of the actual energy supplied (in kWh) over a period divided by the maximum demand in kW over that period, multiplied by the time period selected (i.e. actual energy supplied divided by potential energy supplied). It is always less or equal to unity.

$$\text{LF} = \frac{\text{Actual Energy}}{\text{MD (kVA) x PF x t}} \leq 1.0$$

$$\text{MD(kW)} = \text{MD (kVA) x PF}$$

where PF is the power factor.

(See Figure 12.1.1.)

Low voltage (LV)

The range of AC voltages up to and including 1 000 V r.m.s. (see SABS 1019:1985 for a full definition).

Maximum demand (MD)

The highest averaged electrical demand for a specified period. Typically, 5 to 60 min and 30 min are normally used as these are close to the thermal constant of transformers and lines. (See Figure 12.1.1.)

Medium voltage (MV)

The range of AC voltages exceeding low voltage, up to and including 44 kV. (See SABS 1019:1985 for a full definition.)

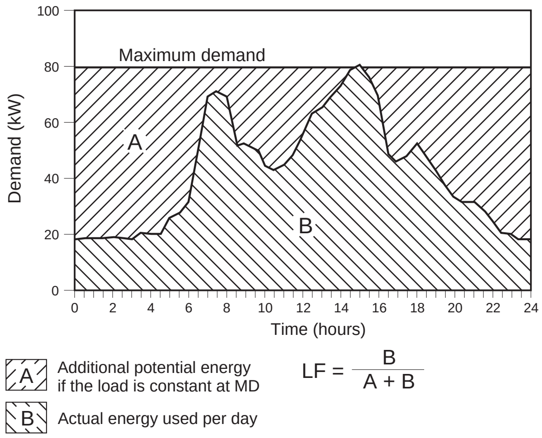

Figure 12.1.1: Typical daily demand curve

STATUTORY VOLTAGE LIMITS

The South African statutory voltage limits for the supply voltage to residential consumers have been summarised from Government Notice No R103 of 26 January 1996, which amended Regulation 9 of the Electricity Act (No 41 of 1987).

This notice stipulates that:

a) for nominal system voltages lower than 500 V, the supply voltage shall be the standard voltage;

b) in the case of a distribution system with a nominal system voltage lower than 500 V, the supply voltage shall not deviate from the standard voltage by more than 10%; and

c) the Board (i.e. The National Electricity Regulator) may on application permit other deviations from the stipulated supply voltage and frequency.

The statutory voltage limits imply that all new networks must conform to the standard voltage of 230 V ± 10% or 253 V maximum and 207 V minimum at the point of supply.

Typically, economic studies indicate the economic apportionment of voltage drop, to meet the statutory limits of 230 V ± 10%, is to aim for an approximately 8% voltage drop on the LV distributor, including service connections. This figure can be increased to 9% or even a bit higher, provided that the regulated busbar is electrically close to the electrification area and steps can be taken to make the LDC (load density classification) of the transformer respond only to the electrification area feeder's loading.

NOTES

- A further 5% voltage drop is permissible within the customer's premises (see SABS 0142).
- The assessment method for calculating the voltage from sample measurements is described in NRS 048-part 2.
- The regulated MV busbar must be controlled via LDC setting and electrification area distribution transformer tap positions (if fitted), to maintain at least 230 V during heavy load periods and not exceed 230 V + 10% during light load periods at the MV transformer's LV output.
- Care should be taken to limit the voltage drop in LV service cables near the end of LV distributors to less than 2% (using the appropriate undiversified ADMD), especially where long looped services supply a number of consumers.

ANALYSIS SOFTWARE

The availability of personal computers has led to the development of programs to assist with the analysis of networks. These packages are in some cases available from the market, but also from consultants and the network planning departments of electricity suppliers.

Three types of systems are available: ADMD modelling, low voltage simulation and electricity loss modelling.

ADMD modelling

An After Diversity Maximum Demand modelling approach is based on appliance usage information to calculate the ADMD, maximum demand, energy consumption and monthly electricity costs for any domestic community.

NOTE: This method should be used with extreme caution, because to obtain valid data on appliance availability and usage requires specialist market research.

Low voltage simulation packages

These are low voltage network simulation packages that integrate MV/LV transformer, LV distributor and service cables using per-phase analysis techniques. ADMD figures obtained from other systems are used as input.

Electricity loss modelling

This involves electrification loss-management systems that may be used to monitor system losses for implemented projects, or as design tools during the planning stage to help with network optimisation.

LOAD FORECASTING

Load forecasting impacts on the whole network plan, as well as capital expenditure. Residential township load forecasts focus on ADMD forecasting over a 15- to 20-year period, which reflects the economic life of the plant. ADMD is used for MV/LV transformer sizing and to calculate voltage drop over the LV feeders, service cables and MV/LV transformers.

Final vs initial ADMD

Two ADMD figures should be determined prior to any other analysis work or technology decisions:

- a seven-year (initial) ADMD figure is required to determine the first phase of the future master plan; and
- a master plan ADMD (final) for loads in 15 to 20 years' time is the major influencing parameter that determines the masterplan settlement layout.

Essential to the viability of the project is the use of a phased upgraded plan that progresses from the initial plan towards the master plan, using the respective ADMD values.

How to estimate ADMD

Three acceptable methods of determining the ADMD figures can be used:

Appliance model

This has an approach or design basis that models domestic appliance behaviour over the peak hour to estimate the appliance's contribution to the ADMD and the expected energy consumption per appliance per month.

This technique gives the planner the information required to forecast individual energy and demand requirement forecasting for the electrification area, and is the preferred method for ADMD determination.

NOTE: Recent experience with this method indicates that, for customers in the high and very high consumption classes, the consumption can be severely underestimated using this method.

Direct measurement

The ADMD may be determined by measuring the maximum demand of a representative existing suburb over the peak month (typically winter for Johannesburg). The suburb in question must ideally have been electrified for many years to yield the correct ADMD figure. If that suburb was provided with electricity only five years previously then a five-year ADMD figure will be determined, whereas the aim should be to establish a 20-year ADMD figure.

This method may therefore prove inappropriate for recently electrified suburbs.

Non-residential loads (such as for schools, hospitals and small industries) must be excluded from this measurement exercise to ensure homogeneity (only the peak time contribution of these loads must be subtracted from the overall measured ADMD, to take non-residential diversity into account).

Therefore,

$$\text{MD}_{\text{residential}} = \text{MD}_{\text{total}} - \text{MD}_{\text{non-residential}}$$

Energy load factor method

A further approach is that used where energy sales forecasts are available. The ADMD can be determined by estimating a load factor at suburb level, which is typically between 25% and 45% (if the individual DSP-level load factor is used then the ADMD will be undiversified, i.e. the demand for one DSP would be determined).

Example:

For a suburb the expected 20-year horizon for energy sales is estimated to be 2 400 units per annum, with expected sales of 1 440 units per annum after seven years.

The annual load factor for the township is estimated to be 26% for both time horizons.

Therefore,

$$\text{ADMD}_{\text{final}} = \frac{\text{kWh}}{\text{LF x h}} = \frac{2\ 400}{0{,}26 \text{ x } 8\ 760} = 1{,}1 \text{ kVA}$$

$$\text{ADMD}_{\text{seven}} = \frac{\text{kWh}}{\text{LF x h}} = \frac{1\ 400}{0{,}26 \text{ x } 8\ 760} = 0{,}6 \text{ kVA}$$

NOTE: The calculations are more appropriately done over annual periods than monthly periods, because there are significant differences in both consumption and load factor in different months.

CONSUMER CLASSIFICATION

Consumption classification

Consumers can be divided into classes according to annual consumption and appliance utilisation. NRS 034-1, Table 2, provides guidance for ADMD figures according to broad categories of consumption class. This table is given in Table 12.1.1 below, with annual load factors at suburb level (full diversity) added. These load factors have been derived from the NRS Load Research Project.

The results of investigations to correlate the annual energy consumption of consumers, the major classification characteristics of the consumers and the expected ADMD have been recorded in a report on the NRS Load Research Project, which is continuing. The results have been used to derive the planning parameters set out in the second edition of NRS 034-1.

Consumption classification can be derived from appropriate market research programmes and economic studies for each area to be electrified. This type of work is usually undertaken by consultants with the necessary marketing and engineering background.

$$\text{ADMD (N)} = \frac{\text{MD}_{\text{residential}}}{\text{DSPs}}$$

provided that DSPs > 100, to allow for full diversity.

If DSPs < 100 then adjust the ADMD as shown in Table 12.1.1.

Load density classification

Load density (kW/ km^2), which is a function of ADMD and stand size, is a very useful aid when selecting technology and calculating voltage drop. Table 12.1.2

Table 12.1.1: Consumption class

CONSUMPTION CLASS (SEE 4.3.3.2 OF NRS 034-1)	APPROX. FINAL LOADING AND DESIGN ADMD (kVA)	APPROX. ANNUAL LOAD FACTOR (%)	APPROX. kWh PER ANNUM
Very high	> 6	> 42*	> 22 000
High	3 to 6	35 to 42	9 200 to 22 000
Medium	1,5 to 3	31 to 35	4 100 to 9 200
Low	0,5 to 1,5	29 to 31	1 200 to 4 100
Very low	≤ 0,5	28 to 29	< 1 300

* In the very high consumption class, there might be demand-side management techniques, such as the application of ripple control that would influence the load factor.

Table 12.1.2: Domestic density classification

DOMESTIC DENSITY CLASSIFICATION	STAND SIZE (m^2)	AVERAGE LOAD DENSITY (kW/km^2)
URBAN:		(ADMD min = 0,5 kVA ADMD max = 4,5 kVA)
High density (HD)	<1 000	500 to 30 000
Medium density (MD)	1 000 to 4 000	300 to 5 000
Low density (LD)	4 000 to 20 000	100 to 1 500
RURAL:	>20 000	0,5 to 250

can be used to select a settlement's domestic density classification.

PLANNING PROCEDURE

A planning procedure based on an approach agreed upon between municipal engineers and Eskom is set out in NRS 034-1.

The recommended method for calculating voltage drops on LV distributors is to use the Herman beta algorithm described in NRS 034-1. The basis is statistical, and it can be conveniently implemented using spreadsheet software.

Available technologies

Currently available technologies for South African residential areas are:

- Conventional three-phase system with transformation from three-phase medium voltage to three-phase low voltage (e.g. 22/0,4 kV).
- Conventional single-phase system with transformation from medium voltage using two phases to single-phase low voltage (e.g. 22/0,23 kV).
- Intermediate voltage system using three-phase medium voltage source, stepping through two voltage transformations, first to an intermediate voltage and then to low voltage using either single- or three-phase alternatives (e.g. 22/3 kV, 3/0 kV, 4 kV for the three-phase option or 22/1 kV, 9/0 kV, 23 kV for the single-phase option).
- MV/LV maypole system for rural areas. This system usually employs smaller transformer sizes and the low voltage network consists only of service cables (e.g. 22/0,23 kV).
- Single wire earth return (SWER) system for very low loads and remote areas where the earth is used as a return load current path. The SWER line could, for example, be designed to be 22 kV between the ground and the single overhead wire (e.g. 22/0 kV, 23 kV).

Table 12.1.3 indicates the applications of these technologies for various domestic density classifications. For high-density urban applications the conventional three-phase system is the only appropriate one to use. For rural networks any system may be appropriate depending on the local conditions - even conventional three-phase systems may be used on a small scale where high-density pocket load areas are present. Economics will govern the decision-making process.

Table 12.1.3: High level preliminary technology selection

DOMESTIC CLASSIFICATION	TECHNOLOGY
URBAN high density (HD)	i
Medium density (MD)	i, ii
Low density (LD)	i, ii, iii
RURAL	i, ii, iii, iv, v

Planning steps

The following are the recommended steps for each of the selected technologies and their alternatives (test against a single representative sub-area to minimise optimisation time):

1. Select the domestic load density classification from Table 12.1.2.
2. The expected ADMD of the community can be determined for the five- to seven-year initial investment period and the final ADMD for the master plan using appropriate software and the information obtained from marketing surveys.
3. Do a high-level preliminary technology selection from Table 12.1.3. Various technologies would generally apply at this point.

4. Each selected technology constitutes a range of alternatives that must be tested to obtain the optimum arrangement of that specific technology. Therefore, choose the various conductors and transformer sizes to be evaluated to establish alternatives for each technology.

5. Determine the maximum feeder distance (intermediate voltage feeder, LV feeder or service connection, depending on the technology).

6. Determine the maximum number of feeders for each transformer size (intermediate voltage feeders, LV feeders or service connections, depending on the service cables - e.g. 22/0,23 kV).

7. Determine the total loss (kW) per configuration.

8. Determine the maximum number of DSPs per configuration.

9. Determine the cost for each configuration, including the cost of losses, plot these costs for each technology and choose a few of the lowest-cost options, keeping flexibility in mind for the masterplan.

   The various arrangements for each technology will produce an economic comparison or trade-off between transformer sizes and cable size. A typical result using this method is illustrated in Figure 12.1.2, which in this case produced an optimum LV feeder length of approximately 6.5X m. The graph is non-linear because, in general, larger cable sizes will be used for longer distances. The transformer and cable sizes that satisfy this minimum point should be used as the selected alternative for the technology.

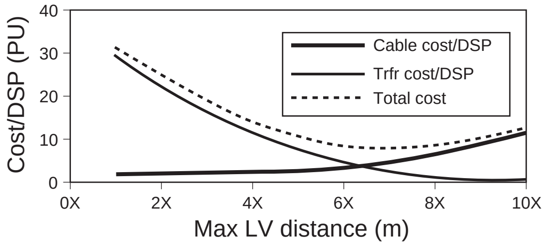

Figure 12.1.2: Economic trade-off

10. With the above information, identify the transformer supply areas from the layout for the chosen options, while maintaining flexibility for phased implementation.

11. Route the maximum number of LV feeders from the transformer positions, considering the information obtained from Step 6 for each option.

12. Calculate the voltage drop in a few typical and worst-case transformer supply areas. Change the feeder routes or lengths, if necessary, to meet voltage drop and conductor thermal constraints.

13. Complete the various design layouts to generate a bill of structures.

14. Use standard material costs to determine the masterplan cost and add the cost of losses using the guidelines in NRS 034-1.

15. Select the phased upgrade plan that defers the largest amount of the five- to seven-year capital cost, but will enable easy and inexpensive upgrading when the load materialises.

16. Life-cycle loss modelling forms an essential part of optimisation. It is therefore important that a simplified electrical layout model be subjected to loss calculations, to ensure optimal system loading. Do an energy-loss calculation, using appropriate software, and ensure close to equal load vs no-load transformer losses.

Area load densities

It is necessary to determine the load densities in kW/km^2 for the area under consideration. This value can be used to help with the preliminary selection of technology and sizing of transformers.

The first step is to determine the total load for the area by multiplying the final ADMD by the total number of DSPs.

Area load = ADMD x DSPs (kW)

Second, determine the total area to be supplied, excluding open spaces such as parks etc (in km^2).

<u>Example:</u>

ADMD = 1,2 kVA, DSPs = 1 500, Area = 1 km^2

Total load = 1,2 x 1 500 = 1 800 kW

Load density = 1 800 kW/km^2

Transformer supply areas

A maximum LV distributor length can be calculated using the stand size and ADMD. The area to be served by a single transformer is roughly described by a circle with radius equal to the distributor length.

Transformer supply area = πR^2

If R = 300 m then trfr. sup. area = 0,28 km^2

For a load density of 1 800 kW/km^2

Transformer load = 0,28 x 1 800 = 500 kW

A suitably rated transformer, taking account of its overload capability and the cyclic nature of the load, can be selected from the preferred sizes in the relevant specification (SABS 780:1979). For this example a transformer rated at 315 kVA would typically be suitable.

Master plan layout

The planner may start by drawing transformer supply circles on a site plan of the area. These circles have radii equal to the maximum LV distance that is allowed. Some overlap in the circles will naturally occur. Transformers may be positioned approximately in the centre of the circles. The entire LV layout can be established by working systematically from one end of the site to the other, making use of appropriate software to simulate voltage drop in the conductors. MV conductors may be modelled using load-flow software.

Practical considerations

After selecting the best technology option and arrangement for a particular settlement, the planner needs to do a complete electrical layout design and the following practical considerations are useful:

Initial layout

As discussed earlier, the initial phase is usually determined using the expected ADMD after seven years.

Installing only every second transformer planned for the master plan can reduce the number of transformers installed. The worst-case LV layout should be modelled to ensure acceptable voltage criteria, using the longer LV distributors (to the positions of those transformers removed). An alternative approach is to have reduced cable dimensions or single-phase arrangements for the initial layout, but then upgrading will be more costly.

MV operating criteria

The planner can determine the best MV system operation by specifying the location of normally open points, etc. MV voltage drop calculations are usually straightforward since, for the most part, only balanced three-phase alternatives are considered, with diversity allowed for as a scaling factor in repeated calculations.

It is important not to under-design the MV network, since this could be costly to replace at a future date. Use the maximum MV/LV transformer loads as point loads and do not diversify further. This will ensure sufficient MV line capacity to cater for future masterplan loading conditions.

Optimisation for urban application

Optimisation studies carried out in the electricity supply industry (ESI) used models that calculate, for high-density urban electrification application, the following information for various technologies:

- maximum distance per feeder;
- number of feeders to be supplied from a transformer;
- maximum transformer load;
- maximum number of consumers in transformer zone; and
- system losses.

From these results the total costs of all the configurations were determined and compared.

It was found that a three-phase LV design is optimal for high-density urban environments.

For stand sizes below 400 m^2, the use of three-phase LV 315 kVA transformers and a 35 mm^2 aerial bundled conductor (ABC) was in general the most cost-effective. For stand sizes between 400 m^2 and 1 000 m^2 the use of three-phase LV 200 kVA transformers and 70 mm^2 ABC was the most cost-effective alternative. In a medium density urban environment the best three-phase LV alternative was also found to be a 200 kVA transformer and 70 mm^2 ABC combination.

Single-phase LV and centre-tap LV designs were not only more expensive for this application, but exhibited the following disadvantages:

- limited reach;
- low efficiency;
- the centre-tap LV system will have imbalances in the primary system, although the secondary system is balanced; and
- the centre-tap LV transformer can only be loaded to 86% of its capacity.

Nevertheless, single-phase, dual-phase and SWER systems may often be more cost-effective alternatives for rural/low density applications.

Areas of cost saving

Although every system might potentially benefit from being uniquely designed, there is often a penalty in both design cost and time, and the cost of using non-standard items. Given resource constraints, the use of a limited selection of preferred sizes of standardised items should lead to overall cost savings. Most of the items that are used in electrification projects are the subject of NRS specifications that specify preferred sizes/types/ratings as agreed by electricity suppliers, through the Electricity Suppliers Liaison Committee (see Appendix A).

Practical examples:

- Depending on the ADMD, a first-time capital cost saving of between 5% and 25% can be achieved using 315 kVA transformers and 35 mm^2 ABC compared to designs using 100 kVA transformers and 35 mm^2 ABC.
- In low and very low consumption areas the use of 4 mm^2 service conductor rather than 10 mm^2 can result in further incremental savings.

Pre-payment systems

It was evident from the studies that the electricity dispenser (ED) and ready board (RB) are the two components that have a significant influence on electrification costs.

A clear strategic direction for domestic metering needs to be developed to optimise business functionality requirements, technology standardisation, and cost, especially for rural areas.

It is also clear that a phased-implementation approach will result in considerable savings due to the initial cost reduction and delay in capital expenditure.

For low and very low consumption areas, an alternative is the use of an "electricity control unit" (ECU) that combines the functions of a prepayment meter and a ready board into one housing. Typically this option will be suitable for consumers with a maximum supply requirement of 8 A.

LV VOLTAGE DROP CALCULATIONS

Voltage drop calculations seem straightforward and easy until phenomena such as diversity between consumer currents and unbalanced network loading become important facts to consider.

Recent research in South Africa has shown that the deterministic method used to calculate voltage drop, which was derived empirically and adapted from methods used in the UK, frequently overestimated the consumption and did not take account of all influencing factors. It also assumed a Gaussian distribution of customer loads, and the research has shown that the distributions are skewed, being better modelled as beta distributions.

Recommended method for voltage drop calculation

Herman beta methodology

The technique described in the second edition (1997) of NRS 034-1 takes account of important research that gave rise to the Herman beta methodology, which takes account of the statistical nature of residential loads and is sensitive to all influencing parameters. This is the recommended method for voltage drop calculations. It is intended that the factors applied will be reviewed and - if necessary - amended, as additional information is derived using data from the NRS load research project (see the section on "consumption classification" above).

Alternative method for voltage drop calculation

Monte Carlo simulation

A full Monte Carlo simulation implementation procedure can be used to simulate the actual network behaviour during peak periods. It is necessary to model the consumer load characteristics around domestic peak consumption periods to provide a load model for the simulation software.

However, the method is generally impractical for use in electrification project design, as it is time-consuming owing to the large number of simulations required. Its use is normally confined to applications in research.

Two methods of allocating consumer loads may be used: direct measurement of consumer currents and the use of statistical distribution functions.

Measurement of consumer currents

Metering equipment can be installed at randomly selected customer installations within a homogeneous group of customers. It is essential that the total group has the same classification to ensure similar energy-usage behaviour patterns. Current measurements at each installation, averaged over five-minute intervals, provide adequate resolution to capture the dynamic behaviour of individual customer currents.

Summation of all the customers' currents will produce a diversified profile over the selected measurement period. The peak day and peak five-minute period can then be selected. This summated current, divided by the number of DSPs gives a diversified maximum current per DSP. A kW value for ADMD is used, which is simply:

$$ADMD = I \text{ x } V_{nom}$$

with I the ADMD current value at time of peak, and V_{nom} the nominal LV phase voltage = 230 V.

SERVICE CABLE CONNECTION STRATEGIES

Service cable phase connections may have various configurations, and decisions regarding how many phases to take from each node or pole and how to arrange subsequent connections to minimise voltage drop must be made. One of the largest contributing factors to voltage drop in LV networks is the presence of neutral currents due to unbalanced loading conditions. Not much can be done about the behaviour of consumers and technical imbalance minimisation techniques must be provided.

Oscillating vs non-oscillating connections

It can be shown that an oscillating phase connection strategy is the best solution. The following explains the application of oscillating and non-oscillating phase connections. All examples use four service connections per node (pole or kiosk).

One phase per node

Planners often design electrification projects to cater for single-phase service cable take-off points via pole-top boxes or the equivalent. This is the simplest method of servicing individual households.

One phase per node, non-oscillating (RWB-RWB):

NODE	RED	WHITE	BLUE
1	4	0	0
2	0	4	0
3	0	0	4
4	4	0	0
5	0	4	0
6	0	0	4

One phase per node, oscillating (RWB-BWR):

NODE	RED	WHITE	BLUE
1	4	0	0
2	0	4	0
3	0	0	4
4	0	0	4
5	0	4	0
6	4	0	0

This connection strategy results in much improved balanced loading conditions and a significant reduction in neutral voltage drop.

Two phases per node

Oscillating phase connection taking two phases out per node produces the following connection arrangement:

RR-WW
BB-BB
WW-RR
RR-WW
BB-BB
WW-RR, etc.

Three phases per node

Oscillating phase connection taking three phases out per node produces the following connection arrangement:

RWBB
WRRW
BBWR
RWBB
WRRW
BBWR, etc.

NODE	RED	WHITE	BLUE
1	1	1	2
2	2	2	0
3	1	1	2
4	1	1	2
5	2	2	0
6	1	1	2

Using three phases per node decreases the voltage dropped as a result of the unbalanced condition by 10-20% over the two-phase per node case. Owing to this relatively small difference it is recommended that two phases be taken out per node and, in addition, that the oscillating phase connection strategy be used.

AREA LOSS MODEL

Planning proposals should include a full technical loss model with analysis results using forecasted energy-usage patterns and associated expected demands. Loss management should be incorporated as a basic requirement for all implemented electrification projects.

DOCUMENTATION REQUIREMENTS

Electrification projects should have a minimum set of documents, which include a planning proposal with the following:

- Maps of the area.
- List of evaluated technology options with technology cost comparisons as described in this document.
- Master plan layout and assumptions.
- Phased-implementation plan.
- MV loadflow calculation results showing system loading, losses and high/low voltages.
- MV/LV transformer and LV distributor plus service connection voltage-drop calculation results, using voltage profiles, LV distributor and MV/LV transformer loading. Results must include the master plan and the phased-implementation plan results.
- Loss evaluation of the system.
- Complete consultants brief if applicable.

See also Table 12.1.4.

Table 12.1.4: Summary of documentation required and examples

MINIMUM INFORMATION		EXAMPLE
1.	**MASTER PLANNING**	
1.1	**Geographical load forecast**	
1.1.1	Domestic final energy consumption (kWh/month)	480 kWh/ month per consumer
1.1.2	Domestic final ADMD (kVA)	2,7 kVA
1.1.3	Domestic load factor (% for 1 000 consumers)	25%
1.1.4	Final number of households	7 000
1.1.5	Bulk loads and notified max demand (no and kW)	2 x 130 kVA and 6 x 70 kVA and 13 x 18 kVA
1.1.6	Bulk loads contributions to peak (no and kW)	2 x 70 kVA and 6 x 20 kVA and 13 x 6 kVA
1.1.7	Electrification area bulk supply demand (kW)	20 600 kW (assumed 7% peak demand losses)
1.1.8	Electrification area supply energy (kWh)	3 700 000 kWh/month (estimated)
1.1.9	Electrification size (km^2)	4,7 km^2
1.1.10	Average domestic sand size (m^2)	400 m^2
1.1.11	Load density of total area (kVA/km^2)	4 100
1.1.12	Load density of pocketed areas (kVA/km^2)	4 100 (no pocket loads in urban areas)
1.2	**Optimised technology selection**	
	Technology type	Conventional MV/LV
	General LV conductor choice (ABC 35 etc.)	35 mm^2 ABC
	Average LV conductor length	
	Max LV conductor length (m)	220 m
	Generally used transformer (kVA)	100/160 kVA ANSI CSP
	Reason for choice	Most economical for high density urban application
1.3	**Optimised voltage drop allocation**	
	Regulated % MV voltage during peak	103,5%
	% MV voltage at MV/LV transformer at peak	101% (lowest MV voltage)
2.	**PHASED-IMPLEMENTATION PLAN (in 5 to 7 years' time)**	
2.1	Domestic energy consumption (kWh/month)	260 kWh/month per consumer
2.2	Domestic ADMD (kVA)	1,8 kVA
2.3	Domestic load factor (% for 1 000 consumers)	20%
2.4	Number of households connected	4 000
2.5	Bulk loads and notified max demand (no and kW)	1 x 130 kVA and 2 x 70 kVA and 9 x 18 kVA
2.6	Bulk loads contributions to peak (no and kW)	1 x 40 kVA and 2 x 10 kVA and 9 x 4 kVA
2.7	Electrification area bulk supply demand (kW)	7 700 kW (assumed 5% peak demand losses)
2.8	Electrification area supply energy (kWh)	1 100 000 kWh/month (estimated)
2.9	Electrification size (km^2)	3,3 km^2
2.10	Load density of total area (kVA/km^2)	2 200
2.11	Load density of pocketed areas (kVA/km^2)	2 200 (no pocket loads)

FINANCIAL CALCULATIONS

Refer to NRS 034 part 1 for details on financial calculation methods.

APPENDIX A

REFERENCE STANDARDS, SPECIFICATIONS AND GUIDELINES

A.1 The NRS rationalised user specifications

The NRS specifications for application in the electricity supply industry are approved for use by the Electricity Suppliers Liaison Committee which comprises, inter alia, representation from the Association of Municipal Electricity Undertakings (AMEU) and Eskom. The committee provides considered choices of planning techniques, codes of practice, recommended practices and preferred equipment, as well as material types, sizes, and ratings, the widespread use of which should lead to overall cost benefits in the electrification drive.

NRS	TITLE
002:1990	Graphical symbols for electrical diagrams Amendment 1 - Index, architectural and reticulation symbols
003-1:1994 003-2:1993	Metal-clad switchgear, Part 1: 1 kV to 24 kV - Requirements for application in the ESI Part 2: Standardised panels
004:1991	Mini-substations, Part 1: up to 12 kV - Requirements for application in the ESI
005:1990	Distribution transformers: Preferred requirements for application in the ESI
006:1991	Switchgear - Metal-encl. ring main units, 1 kV to 24 kV
008:1991	Enclosures for cable terminations in air - Clearances for 7,2 kV to 36 kV
009 Series	Electricity sales systems
009-2-2:1995	Part 2: Functional and performance requirements; Section 2: Credit dispensing units
009-2-4:1997	Section 4: Standard token translator
	Part 4: National electricity meter cards and associated numbering standards
009-4-1:1995	Section 1: National electricity meter cards
009-4-2:1993	Section 2: National electricity meter numbers
009-6-1:1996	Part 6: Interface standards; Section 1: Interface Credit Distribution Unit (CDU) to Standard Token Translator (STT)
013:1991	Electric power cables form 1 kV to 36 kV
016:1995	Code of Practice for earthing of low-voltage distribution systems
017 Series	Single-phase cable for aerial service connections
Part 1:1997	Split concentric cable
Part 2:1997	Concentric cable
018 Series	Fittings and connectors for LV overhead powerlines using aerial bundled conductors
018-1:1995	Part 1: Strain and suspension fittings for self-supporting conductors
018-2:1995	Part 2: Strain and suspension fittings for insulated supporting conductors
018-3:1995	Part 3: Strain and suspension fittings for bare supporting conductors
018-4:1996	Part 4: Strain and suspension fittings for service cables
018-5:1995	Part 5: Current-carrying connectors and joints

NRS	TITLE
020:1991	Aerial bundled conductor - Cable ties
022:1996	Stays and associated components (second edition)
025:1991	Photo-electric control units (PECUs) for lighting
027:1994	Electricity distribution - Distribution transformers - Completely self-protecting type
028:1993	Cable lugs and ferrules
029:1993	Outdoor-type current transformer
030:1993	Electromagnetic voltage transformers
031:1993	Alternating current disconnectors and earthing switches (above 1 000 V)
032:1993	Electricity distribution - Service distribution boxes - Pole-mounted (at 230 V)
033:1996	Guidelines for the application design, planning and construction of MV wooden pole overhead power lines above 1 kV and up to and including 22 kV
034 series 034-0:1998 034-1:1997 034-2-3:1997 034-3:1995	Guidelines for the provision of electrical distribution networks in residential areas Part 0:1998: Glossary of terms (in course of publication) Part 1: Planning and design of distribution systems Part 2-3: Preferred methods and materials for overhead lines Part 3: O/h distribution in low and moderate consumption areas
035:1994	Outdoor distribution cut-outs (drop-out fuses) - Pole-mounted type up to 22 kV
036 series 936-1:1994 036-2:1997 036-3:1997	Auto-reclosers and sectionalisers - Pole-mounted types Part 1: Programmable protection and remote control Part 2: Auto-reclosers with programmable protection Part 3: Sectionalisers
038-1:1997	Concrete poles, Part 1: Concrete poles for o/h distribution and reticulation systems
039:1995	Surge arresters - Application guide for distribution systems
040-1:1995 040-2:1994 040-3:1995	HV operating regulations, Part 1: Definitions of terms Part 2: Voltage colour coding Part 3: Model regulations
041:1995	Code of practice for overhead power lines for RSA
042:1996	Guide for the protection of electronic equipment against damaging transients

NRS	TITLE
043:1997	Code of practice for the joint use of a pole route for power and telecommunication lines
045:1997	Account card for electricity consumers
046:1997	Pole-mounted load switch disconnectors
048 series 048-1:1996 048-2:1996 048-3:1998	Quality of supply Part 1: Overview of implementation of standards and procedures Part 2: Minimum standards Part 3: Procedures for measurement and reporting

A.2 SABS standards

The following South African Bureau of Standards documents may assist in the planning, design and construction of electrical networks in residential areas.

SABS STANDARD	TITLE
97:1991	Electric cables - Impregnated-paper-insulated metal-sheathed cables for rated voltages from 3,3/3,3 kV up to 19/33 kV
152:1997	Low-voltage air-break switches, air-break disconnectors, air-break switch-disconnectors, and fuse-combination units
156:1977	Moulded-case circuit-breakers
171:1986	Surge arresters for low-voltage distribution systems
172:1994	Low-voltage fuses
177 (in 3 parts)	Insulators for overhead lines of nominal voltage exceeding 1 000 V
178:1970	Non-current-carrying line fittings for overhead power lines
753:1994	Pine poles, cross-arms and spacers for power distribution and telephone systems
754:1994	Eucalyptus poles, cross-arms and spacers for power distribution and telephone systems
780:1998	Distribution transformers
1029:1975	Miniature substations
1030:1975	Standard longitudinal miniature substations of ratings not exceeding 315 kVA
1180 (in 3 parts)	Electrical distribution boards
1268:1979	Polymeric or rubber-insulated, combined neutral/earth (CNE) cables with solid aluminium phase conductors and a concentric copper wire waveform combined neutral/earth conductor

SABS STANDARD	TITLE
1339:1992	Electric cables - Cross-linked polyethylene (XLPE)-insulated cables for voltages from 3,8/6,6 kV to 19/33 kV
1411	Materials of insulated electric cables and flexible cords
1418 (in 2 parts)	Aerial bundled conductor systems
1473	Low-voltage switchgear and controlgear assemblies
1507:1990	Electric cables with extruded solid dielectric insulation for fixed installations (300/500 V to 1 900/3 300 V)
1608:1994	Portable earthing gear for busbar systems and overhead lines
1619:1995	Small power distribution units (ready boards) for single-phase 230 V service connections
IEC 60076 (in 5 parts)	Power transformers
IEC 60099-1:1991	Surge arresters Part 1: Non-linear resistor type gapped surge arresters for AC systems
IEC 60099-4:1991	Surge arresters Part 4: Metal-oxide surge arresters without gaps for AC systems
IEC 60129:1984	Alternating current disconnectors and earthing switches
IEC 60265-1	High-voltage switches Part 1: High-voltage switches for rated voltages above 1 kV and less than 52 kV
IEC 60269-1 (in 6 parts and sections)	Low-voltage fuses
IEC 60282-1:1994	High-voltage fuses Part 1: Current-limiting fuses