Section N
Electrical energy

The Neighbourhood Planning and Design Guide

Part II

Planning and design guidelines

Symbols at text boxes

- More detailed information is provided about the issue under discussion
- Important considerations to be aware of are highlighted
- Relevant content from a complementing resource is presented

Developed by
Department of Human Settlements
Published by the South African Government
ISBN: 978-0-6399283-2-6

Version 1. Printed January 2019

human settlements
Department:
Human Settlements
REPUBLIC OF SOUTH AFRICA

Section N
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The Neighbourhood Planning and Design Guide

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N.1 Outline of this section

N.1.1 Purpose

Settlements (and neighbourhoods as the 'building blocks' of settlements) are integrated systems in which various components are interconnected, and this section highlights the role of electrical energy in this system. The aspects addressed in this section play an essential role in achieving the vision for human settlements outlined in **Section B** since electricity supply significantly increases the quality of living environments. In particular, the provision of good quality and sustainable electricity services could play a key role in addressing the challenges facing human settlements as a result of climate change.

Grid-based electricity has historically been the preferred option for energy provision because of its advanced level of development. However, the introduction of embedded distributed generation and off-grid systems, and the drive to use clean energy sources, provide new options for electrifying new or unserved communities.

N.1.2 Content and structure

This section (Section N) is structured to support effective decision-making related to the provision of electricity. The decision-making framework is outlined in Figure N.1 and the structure of this section is briefly described below.

Universal considerations

General aspects that should be taken into consideration when making higher level decisions regarding the provision of electricity are highlighted, including the following:

- The regulatory environment, including key legislation, policies, frameworks and strategies
- The key objectives that should be achieved as a result of the application of the guidelines provided
- Local or international approaches, mechanisms, concepts and current trends that could possibly be utilised to achieve the key objectives
- Contextual factors specific to the development project to be implemented such as the development type and setting

Planning considerations

Factors to consider when making more detailed decisions regarding the provision of electricity are outlined, including the following:

- The characteristics of the development, including the nature of the proposed neighbourhood, the anticipated number of residents and specific features that would have to be incorporated or requirements that would have to be met.
- The existing features of the site and immediate surroundings (built and natural environment) as determined by the physical location of the proposed development.
- Options related to electricity provision that are available for consideration.

Design considerations

Guidelines to assist with the design of electricity systems.

Glossary, acronyms, abbreviations and endnotes

A glossary, a list of acronyms and abbreviations, and endnotes (containing sources of information, explanatory comments etc.) are provided at the end of Section N.

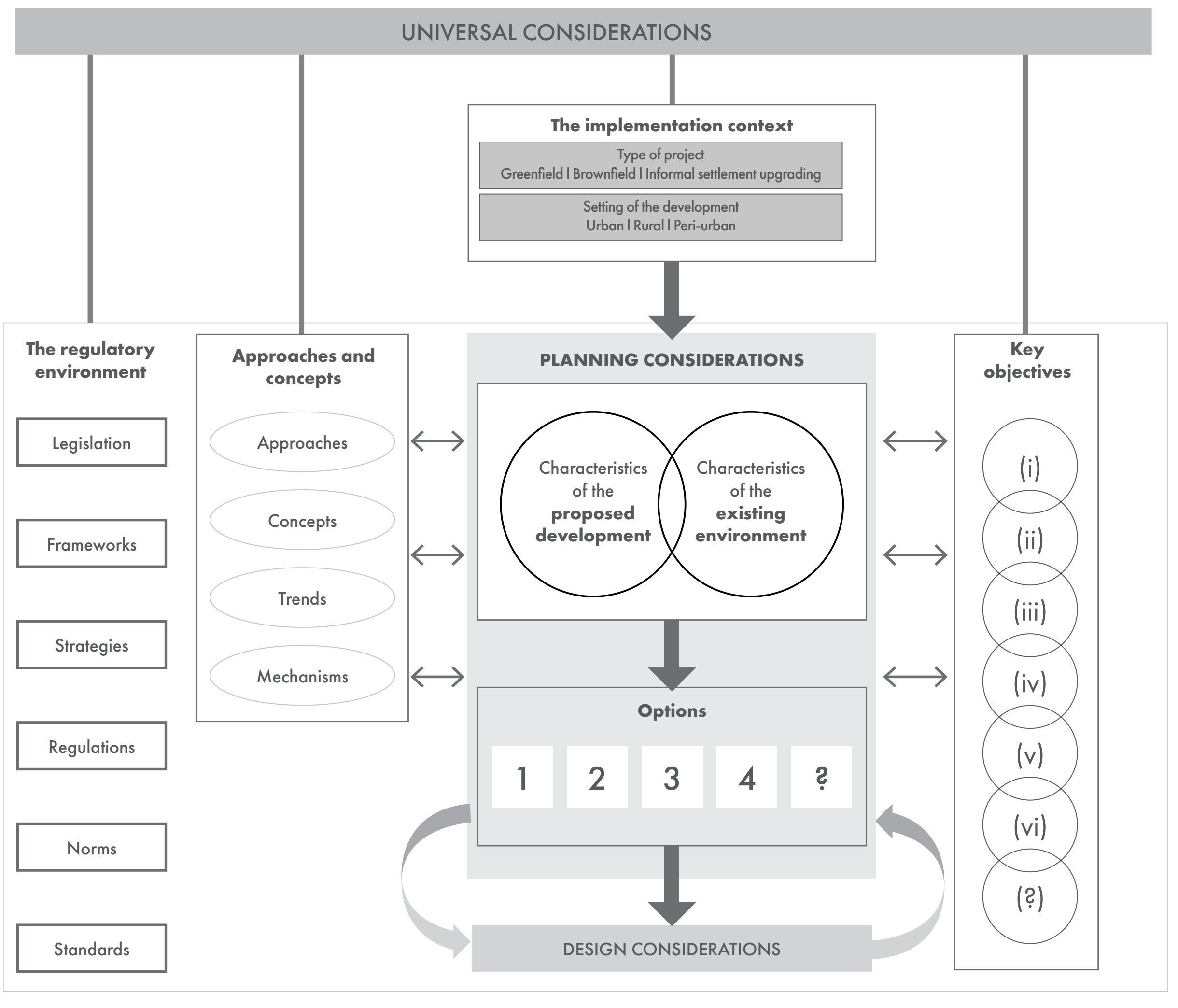

Figure N.1: A framework to assist with planning and design decisions

N.2 Universal considerations

N.2.1 The regulatory environment

The provision of electricity and energy is governed by, amongst others, the Electricity Regulation Act of 2006, the National Energy Act of 2008 and the National Environmental Management Act of 1998, together with their respective amendments. A key document that guides long-term planning for the provision of electricity is the Integrated Resource Plan for Electricity 2010 - 2030, which is intended to be a living document that is updated on a regular basis.

In addition to the above, a range of policies, strategies, plans etc. guide the provision of electricity in South Africa. Some of these documents are briefly summarised below. They are not discussed in detail, so it is important to consult the relevant documentation before commencing with any development.

(i) The White Paper on the Energy Policy of the Republic of South Africa, 1998

The White Paper on the Energy Policy of the Republic of South Africa places an emphasis on the following five key objectives relating to the energy sector as a whole:

- Increasing access to affordable energy services
- Improving energy governance
- Stimulating economic development
- Managing energy-related environmental impacts
- Securing supply options through diversity

(ii) White Paper on Renewable Energy, 2003

The White Paper on Renewable Energy provides a framework for the inclusion of largely untapped naturally available renewable resources into South Africa's energy mix. This White Paper outlines the government's vision, policy principles, strategic goals and objectives for promoting renewable energy such as solar, hydro, biomass and wind in South Africa. This document is complemented by the *Integrated Resource Plan*[1].

(iii) National Climate Change Response White Paper, 2011

The National Climate Change Response White Paper focuses on mitigation and adaptation approaches for the national government to respond to climate change in a manner that ensures resilient, internationally competitive and equitable economic development. The policy identifies the use of renewable energy resources as an important mitigation option in achieving government's greenhouse gas emissions goals.

(iv) Electricity Basic Support Tariff (Free Basic Electricity) Policy, 2003

The purpose of this policy is to support indigent households in meeting their basic energy needs through the provision of a limited amount of electricity to them.

(v) Free basic alternative energy policy: Households energy support programme, 2007

This policy complements the Free Basic Electricity Policy in that it is intended to provide aternative energy to indigent to households in areas that have not been electrified.

N.2.2 Key objectives

Based on the focus areas and objectives highlighted in the policy documents referred to in Section N.2.1, the following three key objectives can be extracted that should be achieved when implementing the guidelines that follow:

- Promote energy security through diversity of electricity supply
- Ensure energy equity by supporting access to affordable electricity services
- Support environmental sustainability by implementing energy systems that minimise negative impacts on the environment and people

N.2.3 Approaches and concepts

N.2.3.1 Grid-based electricity

Grid-based electricity is the supply of electricity coming from the interconnected national electricity grid. This form of electricity can come from a wide range of supply options such as nuclear, coal and renewable energy resources in centralised power stations.

N.2.3.2 Off-grid electricity

The supply of electrical services in the form of a localised grid that is not tied to the national electricity grid is referred to as off-grid electricity (or sometimes non-grid electricity). The supply options in this type of service are mainly renewable energy resources that are usually location specific.

N.2.3.3 Microgrid

A microgrid (also referred to as a minigrid) is a small-scale electricity generation and distribution system that serves a group of localised customers, or loads. A microgrid can either operate as an autonomous system that is not connected to the national electricity grid, or it could be linked to the grid but be able to disconnect and connect depending on circumstances. A microgrid could therefore receive electricity from the grid, and if this is not possible, or if other sources of electricity are utilised, it could operate independently, which is referred to as island mode. Minigrid systems usually make use of renewable energy sources such as solar or wind.

N.2.3.4 Embedded (electricity) generation

Embedded generation refers to the small-scale production of electricity (outside of the national grid), and the introduction of this electricity to the distribution network. Renewable energy sources, usually located close to the place of consumption, are commonly utilised.

N.2.4 The implementation context

This section highlights the contextual factors specifically related to the type of project and the setting of the development that should be considered when making decisions regarding the provision of energy services. Also refer to Section D.2.1 (Type of development) and Section D.2.2 (The setting/location of the planned development).

N.2.4.1 The type of development

(i) Greenfield development

Greenfield projects can theoretically accommodate most types of electricity provision. The deciding factor would normally be the income level of the anticipated residents of the new development, and the availability of electricity supply.

(ii) Brownfield development

The types of electricity systems that could be provided on brownfield sites would be influenced by the nature of the existing physical and socio-economic environment within which the development will be located. For instance, infill developments, retrofitting and the subdivision of large residential stands may all require different types of systems depending on the availability of electricity supply.

(iii) Informal settlement upgrading

Informal settlement upgrading projects are usually complex undertakings that require extensive community participation, specifically with respect to the level of services and infrastructure to be provided. Acceptability and perceptions would be important factors to address when making decisions regarding electricity provision.

N.2.4.2 The setting of the development

(i) Urban

Urban settings can take on different forms, and therefore developments will vary in nature. Urban areas include central business districts, residential suburbs, informal settlements, and what used to be referred to as townships, and this will influence the type of electricity system to be provided.

(ii) Peri-urban

Given the transitional nature of peri-urban areas, the nature of developments will vary considerably, and so will the manner in which electricity is provided.

(iii) Rural

Development sites in rural areas will vary in nature depending on the location, for instance whether it is situated in a rural town or a dispersed settlement. The manner in which electricity is supplied will therefore also vary.

N.3 Planning considerations

This section deals with the planning for the provision of electricity. In this context, the term "planning" means making informed decisions regarding the type or level of service to be provided, and then choosing the most appropriate electricity supply options based on a thorough understanding of the context within which the planned development will be implemented.

Decisions regarding electricity supply have to be informed by a thorough understanding of the features and requirements of the proposed project, and of the context within which the planned development will take place. This would require an assessment of the characteristics of the proposed development. Furthermore, the characteristics of the environment in which the new development will be located need to be examined and possible services and infrastructure that could be utilised should be identified.

This section outlines a range of questions that need to be answered and factors that have to be considered to inform decisions regarding the electricity system to be provided as part of a development project.

N.3.1 Characteristics of the proposed development

Decisions regarding electricity provision need to be guided by an assessment of the characteristics of the proposed development and an understanding of the requirements or needs that will have to be met. Issues that should be considered are discussed below.

N.3.1.1 The nature of the proposed development

Various factors related to the nature of a development could influence decisions regarding the provision of electricity services. For instance, mixed-use, mixed-income projects, and projects that are primarily residential in nature, would need different types and sizes of substations and different electrical network capacities. Similarly, inner city, infill projects would be different from, for instance, an informal settlement upgrading project. The nature of a project therefore needs to be understood to make informed decisions regarding appropriate electrical capacity provisions.

N.3.1.2 The potential residents of the development

Decisions related to electricity provision need to be guided by information regarding the potential residents. Usually, the identities of the actual residents are not known when a development is planned and designed. It may be possible to make assumptions regarding the possible nature of the future residents by assessing the surrounding neighbourhoods or similar developments in comparable locations or contexts. It is important to try to establish the following as far as possible:

- The total number of residents that would have to be accommodated, taking into consideration that actual numbers may be higher than anticipated due to the fact that the provision of houses and services may attract more people than originally planned for. As the population of the area increases, there is likely to be an increase in demand for electricity.
- The number of households and the range of household sizes. This will indicate how much electricity may have to be provided.

- Income and employment levels and spending patterns. This would, for instance, indicate to what extent the households can afford to pay for electricity services and hence would help to plan and design a system that can accommodate the provision of free basic electricity.

N.3.2 Characteristics of the existing environment

To decide on the technology and level of service to be provided, a clear definition of the area to be developed is necessary in order to appropriately scope the required electricity services. Decisions regarding electricity provision need to be guided by an assessment of the context within which the development will be located.

G.3.2.1 The physical location of the proposed project

Constraints and opportunities posed by the site could influence the way in which electricity is provided. The existing features of the area and immediate surroundings (built and natural environment) of the proposed development need to be considered when planning for both grid-based and off-grid electricity systems. Aspects that need to be considered are briefly outlined below.

(i) Topography

The topography of the project site is an important factor that should be considered when making decisions regarding the layout of the development, and as such it will also guide decisions regarding the provision of electricity services for the neighbourhood being developed. Various physical characteristics of the environment, e.g. the slope of the site, streams, hilly terrain and rocky outcrops, will influence the design and installation of infrastructure such as overhead lines, underground cables, substations, wind farms, and solar PV panels.

(ii) Climate

The micro- and macro-climate conditions of the site will have an impact on the type of electricity system suitable for deployment. The site should be physically inspected to assess the climatic changes at different times of the day, preferably even at different times in the year. Physical inspections will provide clues about the suitable location of the electrical infrastructure. The following questions need to be answered:

- Is the site exposed to prevailing winds? Is the wind direction seasonal? This information would assist in deciding whether a wind farm would be a feasible option, and, if so, where it should be located.
- Where does the sun rise and set in summer and winter? Be aware that there may be external features that influence sun penetration on the site, such as a nearby mountain, hill, tree, or building.

(iii) Geotechnical characteristics

The type of soil can sometimes necessitate the use of specialised construction methods or materials. It can also mean that certain areas of the site might not be suitable for the installation of electrical infrastructure. Civil structures may need to be reinforced for different supply and/or network infrastructure e.g. overhead line towers/poles, solar PV installations and wind turbines. The following questions need to be answered:

- What is the soil condition and quality?
- Is the site part of or close to a dolomitic area?
- Was the site used for mining and exploration in the past?

- Is the site subject to seasonal flooding?
- Are there obstacles that would limit sun penetration that cannot be removed?

(iv) Landscape and ecology

The physical features of the landscape could have a substantial impact on the types and positioning of biogas, solar and wind systems, and electrical lines. If the development is located in or near an ecologically sensitive area, there may be restrictions that may influence the positioning (and ease of construction) of the electrical infrastructure. Ensure that information is collected regarding the following:

- The position of any telephone poles, overhead power cables, rock outcrops, water features, dongas etc. that could restrict building work or may require approvals from various government departments.
- Wetlands, surface water bodies or other ecologically sensitive areas on or near the site.
- Endangered or protected animal species on or near the site.
- Existing vegetation, especially trees, and whether they are deciduous or evergreen, indigenous or alien.
- Natural features that may have cultural significance.

(v) Existing buildings on the site

If there are existing buildings on the proposed development site, they can be viewed as either presenting opportunities or constraints. In certain cases, existing buildings could be incorporated into the development by converting them into housing or social facilities. If such buildings are converted, the electricity supply and reticulation network in the area should be planned and designed to be able to accommodate such buildings.

N.3.2.2 Available infrastructure / services

Neighbourhood developments often create additional demand for services and therefore have a potential impact on existing services and infrastructure. The following needs to be established:

- What electrical infrastructure (bulk and local) is available close to the new development?
- What is the proximity of the neighbourhood to existing and planned electrical network infrastructure?
- How far is the neighbourhood from Eskom or municipal transmission/distribution networks?
- What is the status of planned transmission/distribution networks for the area?
- Does existing infrastructure have enough capacity to accommodate the new development?
- Can the new development be linked to existing infrastructure?
- If yes, what is the cost of extending existing transmission/distribution networks for the neighbourhood and/or other proposed developments in the area?
- The cost of off-grid energy supply (wind, solar PV, hydrogen, diesel, biogas and natural gas) and the associated network infrastructure relative to grid-based electricity supply.

It might be necessary to undertake field visits to confirm and complement existing network data for infrastructure such as network equipment, historical loading and performance.

N.3.2.3 Existing socio-economic features

The planning and design of a development have to be guided by the potential needs of the residents of the new and existing neighbourhoods. Where appropriate, the community for whom the proposed project is developed must be involved in the decision-making process from the outset to ensure their concerns are understood and taken into consideration (See Section E).

It is also important to acquire information regarding the socio-economic features of the neighbouring or surrounding communities. This will provide some indication of the Living Standard Measure (LSM) of the new development, and therefore the electricity system required. The following questions should be answered with respect to the existing community (if known) and the adjacent neighbourhoods, especially those that are functionally linked to the development:

- How many people will be living in the planned neighbourhood?
- What is the average size of households in the area?
- What is the income profile of the residents and which living standard measure do households fall under?
- What is the employment profile of the residents?

N.3.2.4 Existing plans and developments

Most of the information and data required to assist with planning electricity services could be obtained from relevant departments within municipalities. As a starting point, a significant amount of raw and processed data can be extracted from the following:

- Spatial Development Frameworks (SDFs)
- Local Economic Development (LED) plans
- Regional electrification plans
- Integrated Development Plans (IDPs)

Demand will primarily be driven by the location and type of development, the existing and planned population demographics as well as the size and socio-economic characteristics of the development. When electricity services have to be provided for a range of population demographics (in particular where low-income households are dominant), the increased demand and consumption after electrification should be taken into consideration during the planning phase.

N.3.3 Electricity systems options

N.3.3.1 Factors to consider

Planning for electricity services for a development is in essence based on capacity requirements (i.e. active power (kW) and not necessarily the energy (kWh)). Due to the stochastic nature of specific household electricity usage, statistical methods are used to derive these capacity requirements (Figure N.2). A key parameter that results from these statistical methods is that of after diversity maximum demand (ADMD). ADMD is the simultaneous maximum demand of a group of households divided by the number of consumers, expressed in apparent power (kVA) (which is very similar to kW but adjusted for the expected power factor). ADMD is discussed in more detail in Section N.4.

A key decision that needs to be taken is whether a grid-based or off-grid electrical service will be used (or a combination of the two). These options are discussed next.

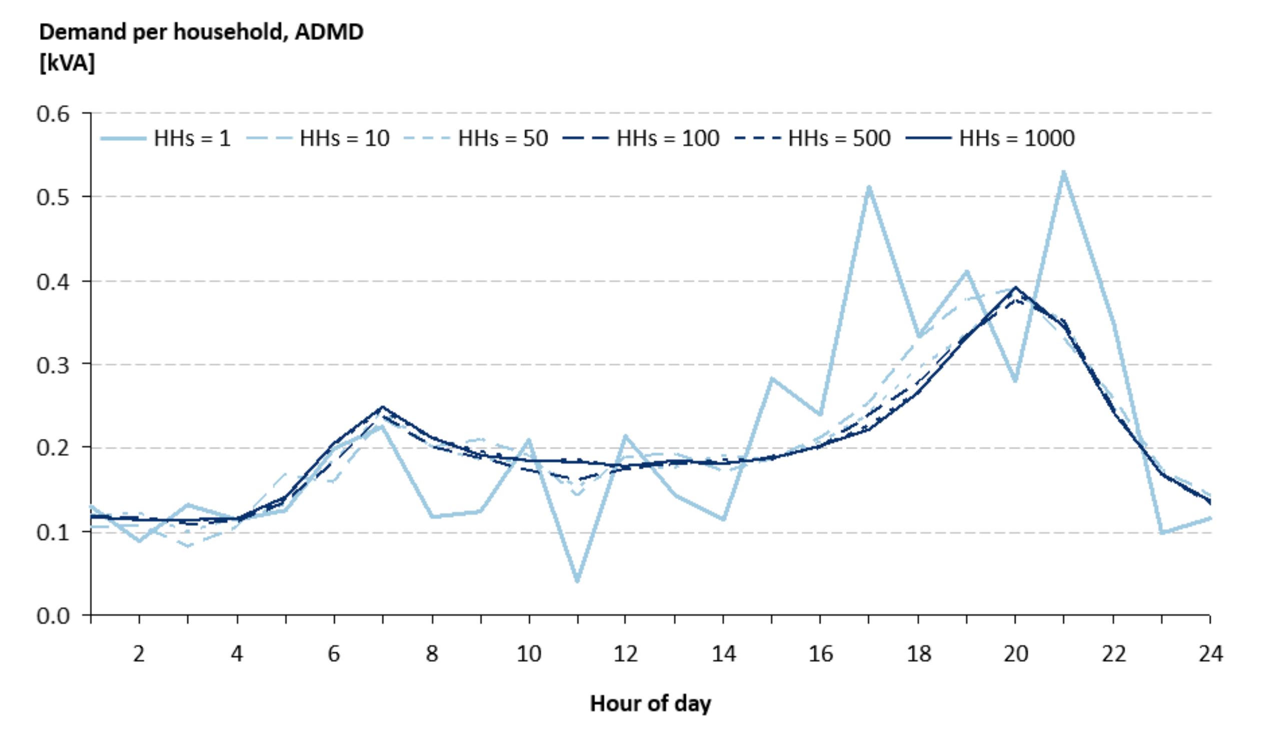

Figure N.2: Electricity demand on a representative day for 1 to 1000 similar households to demonstrate ADMD

N.3.3.2 Grid-based medium voltage and low voltage options

(i) Electricity planning for medium and low voltage networks

There is an important difference between planning a medium voltage (MV) and low voltage (LV) electricity service. MV involves large networks, and MV planning therefore focuses on bulk capacity, while LV planning relates to electricity at neighbourhood and household levels.

Whether the provision of electricity is via a grid-based or an off-grid service, it is recommended that common, standardised MV and LV components are used. This will ensure that an off-grid neighbourhood will be able to connect to the grid if needed without difficulty.

A high-level summary of MV and LV technology options available is provided in Table N.1. The information provided can be used to assist in making decisions regarding the technologies available and their suitability for different types of neighbourhood development.

For high-density (HD) urban applications, conventional three-phase systems are the only appropriate technology (combined with small-scale embeded generation, demand side response and/or storage, where appropriate). For rural networks, any system may be appropriate, depending on local conditions - even conventional three-phase systems may be used on a small scale where HD load pockets exist.

Table N.1: MV/LV options for grid-based electricity depending on the type of development (adjusted from various sources[2,3,4])

Type of development	MV technology[1]	LV technology[2]
High-density, high income urban areas High-density, lower-income urban areas	• Buried three-phase MV cable • 11 kV or 22 kV • Overhead three-phase • 11 kV or 22 kV	• Buried three-phase cable • Overhead three-phase (could use single-phase LV tee-offs)
Medium density (suburb, lifestyle)	• Buried three-phase MV cable • 11 kV or 22 kV	• Buried three-phase cable
Low-density, peri-urban, smallholdings	• Buried three-phase MV cable OR overhead three-phase MV • 11 kV or 22 kV	• Overhead dual-phase in higher-density areas (with single-phase tee-offs) • Single-phase in low-density areas
Rural networks (incl. rural electrification)	• Overhead three-phase MV (backbone) • 22kV preferred • Minor tee-offs: phase-to-phase • SWER tee-offs in very low-density areas • Phase-to-phase and SWER tee-off loading limited to ≤ 400kVA and ≤1% voltage unbalance per tee-off • MV induced voltage unbalance ≤0.8% and ≤1.5% for predominately three-phase and single-phase networks respectively	• Overhead dual-phase in higher-density areas • (with single-phase tee-offs) • Single-phase in low-density areas • Three-phase to large end-users (pumping loads etc.)

[1] MV = nominal voltages greater than 1 kV but lower than 44 kV; in practice these would be 11 kV, 22 kV and 33 kV.
[2] LV = 230 V single-phase to neutral, 400 V phase-to-phase, 460V phase to phase-to-dual phase (230V phase to neutral).

When planning MV and LV electricity services, it is important to also consider aspects related to sub-transmission level grid networks. Sub-transmission level networks are below transmission level but above MV/LV levels (typically 44 kV, 66 kV or 88 kV). Factors to consider include the following:

- The provision of sub-transmission network infrastructure involves long lead times, substantial servitude requirements, and, if not planned for in good time, will result in significantly increased costs as a result of the possible deployment of sub-optimal technologies, e.g. buried HV/MV cables and compact (sometimes underground) substations.

- The HV/MV substation(s) that will be used as the source from which the MV/LV grid-based electricity is going to be supplied should be known. It should then be determined if the substations have sufficient capacity available, or whether upgrades will be required. Upgrades could include adding transformation capacity, bus-bar extensions, an additional feeder bay or even a new HV/MW substation and overhead line(s).

The construction periods for MV grid infrastructure are shorter than for sub-transmission infrastructure, but can still be significant. The following should be considered:

- MV overhead lines and buried cables require servitudes and therefore the planning of routes should be sufficiently integrated with other aspects of spatial planning and design, e.g. roads, subdivisions and public open space.
- The number of MV feeders, feeder lengths and cable/conductor sizes is dependent on the magnitude of expected demand as well as the spatial characteristics of the neighbourhood.

(ii) Small-scale embedded generation, demand side response and energy storage

Small-scale embedded generation (SSEG), aggregated demand side response (DSR) and/or energy storage can be summarised as follows:

- SSEG complements existing network technologies and could also be deployed at household or community levels for partial/full self-supply of electricity needs. This could include solar PV panels, micro-hydro, and wind or biomass/-gas supply technologies. These would then be connected at LV level via either single-phase or three-phase connections.
- DSR at neighbourhood level involves the management of the demand placed on an electricity network by all the household appliances combined (the aggregate demand) at specific times to reduce the electricity required, rather than having to increase the electricity supply to meet peak demands.
- Energy storage is a useful mechanism that could be used to ensure that a particular network has a stable and reliable electricity supply. It involves the storage of electricity during periods when demand is low, and the utilisation of the stored electricity during peak times when the demand for electricity is high.

(iii) Reliability of supply

The reliability of electricity supply is an important factor to consider when designing grid-based electricity services. For sub-transmission as well as MV/LV networks, the System Average Interruption Duration Index (SAIDI) is usually used to measure reliability. The SAIDI is an indication of the average duration of customer interruptions within a particular area. A good SAIDI means that customers will be without electricity for shorter periods of time.

In addition to the reliability of a service, the cost of unreliability (the cost of customer interruptions) should also be considered. This is referred to as the cost of unserved energy (COUE). COUE can be calculated at a high level for a homogenous group of households, or it can be disaggregated into LSM categories as a function of the demographics for the neighbourhood. Neighbourhoods with higher concentrations of higher LSM level customers would have a higher COUE, whilst electrification of settlements in rural areas and informal settlements would have a lower COUE. This is an important planning consideration, as it defines the acceptable level of energy service to the proposed development (the reliability of the service). As a result, it has direct implications for the required investment in network infrastructure. For more information, refer to the *Distribution Network Code*[5].This code sets the basic rules of connecting to the distribution system and specifies the technical requirements to safeguard the safety and reliability of the distribution system to ensure that all users of the system are treated in a non-discriminatory manner.

N.3.3.3 Off-grid technology options

(i) Resource assessment

To guide decisions regarding off-grid technologies, information regarding potential energy sources and resources is required. An assessment should be conducted that would provide answers to the following questions:

- Which energy resources are available and in what quantity?
  - Non-renewable e.g. coal, natural gas, diesel/petrol
  - Renewable e.g. wind, solar, biomass/biogas, water
- Which technology can be used to produce electricity from these energy resources?
  - Solar: concentrated solar power (CSP), solar photovoltaics (PV)
  - Wind: Wind turbines
  - Waste/animal residue/biomass: gasification systems, steam turbines, engines
  - Water: turbines, electrolysis (hydrogen)
- What are the costs for producing energy with these technologies (now and in the future), i.e. life cycle costs, levelised cost of electricity including capital expenditure, operational expenditure and other costs?

Guidance on the planning of off-grid electricity services is available in the IEC/TS 62257 series[6].

(ii) Microgrids

Microgrids can be implemented in both grid-based and off-grid electricity systems. However, they are predominantly used in off-grid applications, and mainly for rural electrification. See Section N.2.3.3 for a brief description of microgrids.

A microgrid system could be an appropriate option under certain circumstances for the following reasons:

- They contribute to the drive towards clean energy and resilient infrastructure.
- They are less susceptible to grid-based electricity outages.
- By enabling the use of locally sited energy resources such as liquid fuels, wind, solar, hydro or biomass/biogas, microgrids may diversify a neighbourhood's energy portfolio.

During the microgrid planning phase, it is important to carry out detailed feasibility studies to ensure the investment is justified. A substantial initial capital investment is required, which can vary widely depending on the specific circumstances of the project. The lifetime cost of the system should also be carefully assessed to ensure that long-term financial commitments with respect to ongoing management and maintenance are taken into consideration. These costs need to be considered in conjunction with potential cost savings that could be achieved over a period of time, and the revenue that the system will generate.

A comprehensive assessment needs to be conducted to assist in determining the return on investment and bankability (e.g. attractiveness in terms of cashflow, future earnings, probability of securing financing etc.) of the project to enable customers/investors to make informed decisions about the viability of the microgrid project. The advantages and disadvantages of different financing options also need to be evaluated. Funding sources may include customers themselves, private investors or other third parties, government departments and entities, local utilities or municipalities, or a combination of these.

It is important to note that financial viability (bankability) is not always the only criterion that should be taken into consideration when deciding whether or not a microgrid system should be provided. Other factors that could influence decisions include the proximity of the proposed development to the existing grid, the impact of grants and subsidies on the viability of the system, the need to be (or not be) independent of the grid, and access to reliable energy sources. In some cases, minigrid systems may be the most appropriate way of providing rural communities with electricity.

N.4 Design considerations

Various software tools are available to assist with the planning and design of electricity systems, and therefore this section does not provide detailed guidance on design calculations.

The Department of Energy has provided guidelines on electrification of informal settlements[7], and the primary consideration is that the design of the grid for servicing informal settlements must comply with planning and design aspects of NRS 034-1[8], the quality of supply specifications of NRS 048[9], and the quality of service specifications in NRS 047[10].

N.4.1 Demand forecasting

Demand forecasting is strongly dependant on the geospatial characteristics as well as demographics and socio-economic characteristics of the neighbourhood development. A number of tools are available that take all the variables into consideration to assist with geospatial demand forecasting. A number of tools have been developed that are applicable specifically to the South African context[11, 12].

A demand forecast for 20 years in 5-year increments and with the lowest possible geographical resolution would usually be necessary. Hourly geospatially disaggregated demand profiles would allow for the determination of the ADMD for the neighbourhood and the accurate design of network infrastructure. The demand can be established on the basis of collected data or applied load sub-classes (based on the number of households, locations and demographics). The sum of these demand profiles will provide the overall demand forecast.

Typical load classes are defined in the *Geo-based Load Forecast Standard*[13] as well as in the NRS 034 series[14]. More information about load classes and the expected demands associated with the load classes is available in the *Distribution Network Planning Standard*[15] and NRS 048-2:2003 .

To account for uncertainty in demand growth, a probabilistic approach to demand forecasting is useful. This means that the possibility of SSEG being incorporated into the electricity service is taken into account when determining demand.

N.4.2 Small-scale embedded generation

As a guideline, the maximum size of an individual generator in an LV network should not exceed 25% of a customer's maximum demand (if on a shared feeder) and no more than 75% of a customer's maximum demand (if on a dedicated feeder). For further information on the integration of SSEG into LV networks, see NRS 097-2-3:2014[17] and the *Grid Connection Code for Renewable Power Plants Connected to the Electricity Transmission System or Distribution System in South Africa*[18]. The purpose of this code is to specify minimum technical and design grid connection requirements for renewable power plants that are connected to, or intend to connect to, the South African electricity grid or distribution system.

All SSEG installations should be either licensed or registered with NERSA. It is also essential to involve the electricity service provider (Eskom or the municipalities) in decisions when considering the implementation of a SSEG system. The following documents are relevant:

- *Requirements for SSEG - Conditions and Application Process to Become a Solar PV Embedded Generator:* The purpose of this document is to provide information regarding the process to follow when connecting solar PV embedded generation to a municipal electricity network.
- *Application for the Connection of Solar PV Embedded Generation:* This is a template application form for the connection of an inverter-based solar photovoltaic generation system to the electrical grid of a municipality.
- *Contract for Embedded Generation:* This is a template contract that clarifies the terms, conditions, rights and obligations of different parties regarding the connection of the customer's SSEG system to the municipal electricity grid.

N.4.3 Quality of electricity supply

The quality of the electricity supplied to an area needs to meet certain minimum standards. Under normal conditions, electrical network equipment should not be loaded beyond acceptable thermal and fault-level ratings as specified in NRS 034-1[19]. Only during abnormal operating conditions should network equipment be operated beyond design ratings, and then for limited periods of time only. Ideally, the maximum limits for equipment shall never be exceeded. When designing network infrastructure, these ratings need to be considered up-front to ensure suitable equipment is chosen, e.g. the correct size of cabling, sufficient transformation capacity and appropriate instrumentation.

To ensure a reliable electricity supply, voltage supply, voltage unbalance, voltage changes, voltage flicker, voltage dips and harmonic distortions should remain within the limits prescribed in NRS 048-2[20]. These standards are applicable to grid-based electricity supply, but it is recommended that similar standards are applied to off-grid systems to ensure compatibility in case it is connected to the grid in future. The integration of renewable energy plants across the HV/MV and LV levels would need to comply with the *Renewables Grid Code*[21].

Rapid changes in renewable energy generation output can cause flickers, specifically from solar- and wind-generated energy. The rapid changes are caused by fast changes in irradiance caused by moving clouds (in the case of PV panels), and rapid changes in wind speed (in the case of wind turbines).

N.4.4 LV network design considerations

The design of a LV network for a neighbourhood is based on the characteristics of the neighbourhood in terms of its layout and structure, and the various components such as roads, lighting, water, housing, open space etc. The available bulk sub-transmission as well as MV capacity should be factored in when doing the design. Other factors that need to be considered include the following:

- The best spatial layouts of MV/LV transformation capacity and LV feeder routing
- The choice of LV technology (three-phase, dual-phase or single-phase)
- Conductor sizing and configuration to supply the required ADMD within technical limits
- Large domestic demand that is not household demand (e.g. local retail, schools etc.). The LV design would need to ensure sufficient capacity for these larger consumers. The cost of the LV network is dependent on the load magnitudes, spatial density and any technology preferences (e.g. preference for buried cable).

A range of powerful tools is available to assist with LV network design. These tools help to create the most suitable designs and to select the most appropriate MV/LV technologies for the particular set of requirements. They are also useful in ensuring the system is cost effective, whilst maintaining statutory voltage drops across the designed network.

Voltage drop calculations are influenced by factors such as the diversity of consumers and unbalanced network loading. Network loading and capacity will change dynamically due to the following:

- Changes in weather
- Storms (high winds, lightning)
- Equipment failures (due to age / lack of maintenance)
- Existing/expected diurnal, monthly and seasonal variations in the demand profile of households and neighbourhoods

Voltage drop calculations

The Energy Research Data Portal of South Africa[22] provides access to valuable data, information and tools. It also makes available software developed as part of the Domestic Load Research Programme, namely the Eskom Distribution Pre-Electrification Tool (DPET) and the Distribution Profile Mixer (DPM).

The Distribution Pre-Electrification Tool is a software application that can be used to predict domestic consumer ADMD (with Herman Beta Parameters), consumption, and the load profile for a group of 60 or more consumers. The Herman Beta probabilistic method has been found to be more reliable than deterministic methods of calculating voltage drop in low voltage feeders. The calculation method is described in NRS 034-1[23].

The Distribution Profile Mixer Tool is a software application for estimating the aggregate hourly load profile for consumers from different domestic consumer classes. It can be used to analyse the total residential load on a feeder or in an area, and to model what-if scenarios for load planning.

LV feeder phase connections may have various configurations. Decisions need to be made regarding the number of phases to take from each node or pole as well as on how to arrange subsequent connections to minimise voltage drop. 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. Automated algorithms in software tools are available to assist with the calculations. Oscillating phase connection strategies are very effective in dealing with phase imbalances and should be incorporating when designing LV networks. Details of some of these strategies are provided in the *Distribution Network Planning Standard*[24].

N.4.5 Design considerations specific to microgrids

When designing a microgrid system, the following should be considered:

- Performance characteristics of energy resource supply options to be used by the microgrid
- Electrical service demand (existing type of load and future demand – future years)
- Number of customers/households

- The availability of land to construct the infrastructure
- Geological characteristics and planned land use developments
- Circuits' physical lengths
- Feeder configuration (networked/radial/looped)
- DC or AC microgrid configuration (or mixed)
- Desired reliability and power quality levels
- Voltage levels to be utilised
- Control and protection methods

According to IEC TS 62898-1[25], microgrids can primarily be connected in three ways, namely using a single bus structure, a multiple bus structure and a multilevel structure. An example of a multilevel structure is illustrated in Figure N.3.

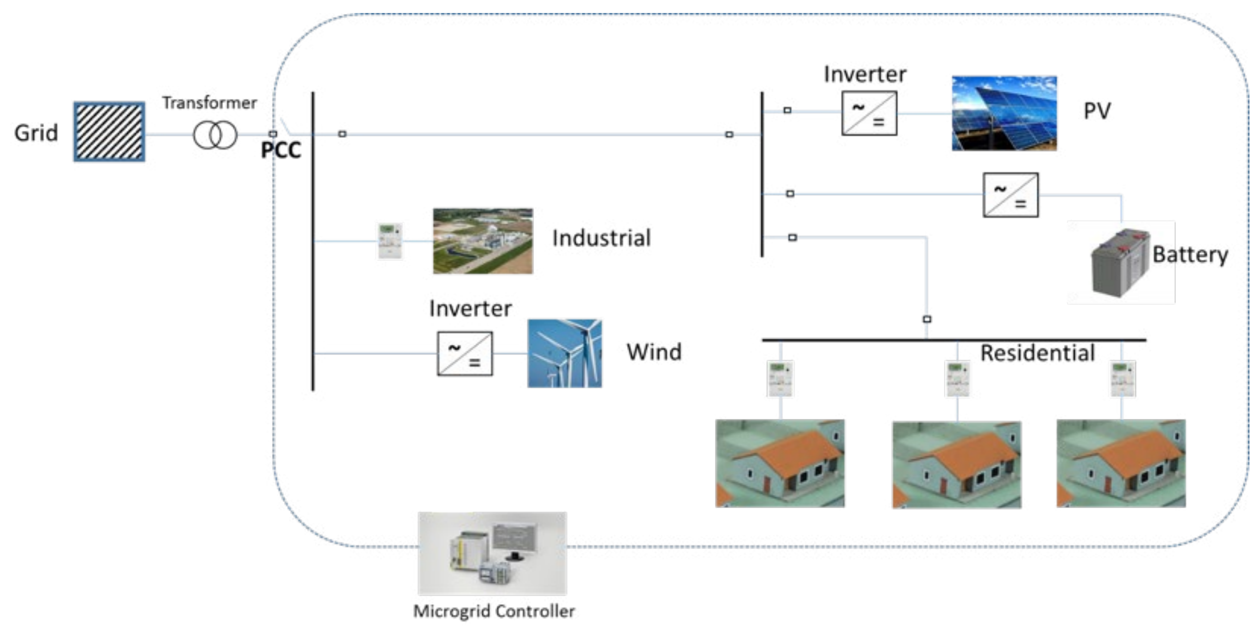

Figure N.3: Typical configuration of a microgrid

The microgrid controller unit should be able to provide energy and power balance of the microgrid in grid and off-grid modes. The controller must be able to communicate with all smart meters, protection relays and switching devices. The point of common coupling (PCC) indicated in Figure N.4 is responsible for switching between modes.

Studies may have to be conducted to ensure that possible challenges related to the integration of distributed generation and the microgrid are identified and effectively addressed. To ensure that the required standards are adhered to when designing a microgrid that will be connected to the grid, certain aspects need to be considered as outlined in IEEE Std 1547.7-2013[26], namely interconnection, equipment loading, unintentional islanding, protection design, coordination, fault rating, voltage regulation and reactive power management, power quality and communication. These aspects are briefly discussed next.

N.4.5.1 Microgrid interconnection

The connection of distributed generation resources requires a significant level of interaction control. Thus, designed microgrid controller units will be required to coordinate the operation of the main grid connection, and integrate renewables and non-renewable generation sources for a stable electrical power network. The microgrid controllable units should operate such that the switch between grid-connecter mode and island mode is made seamlessly. Frequency control, active power and voltage should be managed in both modes, as illustrated in Table N.2.

Table N.2: Characteristics of grid connected and island modes for microgrids

Connection mode	Characteristic
Grid connected	• The frequency control is supported by the grid. • Active power supply is balanced by the distributed resources and main grid. • Voltage and reactive power are managed by the main grid supply.
Island (off-grid)	• Frequency is maintained by the distributed generators. • The active power demand is met by the combination of distributed supply. • The reactive power is met by the distributed generation.

N.4.5.2 Equipment loading

In traditional grid connections, the electrical networks at the distribution level are designed for unidirectional power flow, and unidirectional short-circuit contribution, i.e. from the substation or primary source to the loads. However, in the case of microgrids, the distributed generators may change the power flow and appear to reduce loading. The loss of either the load or the distributed generator may cause equipment overloading. To avoid this, planning studies should be conducted.

N.4.5.3 Unintentional islanding

Network faults are likely to increase the number of unintended islanding in the network. Islanding can be controlled by sectionalising or disconnecting devices. There are many interrupting devices that can be designed to trip and clear a fault and automatically reconnect to restore load. However, an attempt to reconnect into the island unsynchronised with voltage, frequency, and/or phase angle can result in the damage of switchgear, power generation equipment and customer equipment. The unintentional island will also expose users to safety hazards as a result of energised disconnected conductors. This should be designed for in the microgrid to ensure a seamless and safe transition in the event of unintended islanding.

N.4.5.4 Protection design, coordination, and fault rating

Protection systems are designed to reduce the impact of faults that can be caused by lightning or problems in the electrical system. Distributed generation systems need to be coordinated with the protection systems employed on distribution networks. The addition of SSEG to distribution circuits will affect coordination. Protection settings can be oversensitised or desensitised by distributed generation fault current contributions, depending on the location of the existing protective device. Connecting distributed generation resources to a distribution feeder can introduce sources of short-circuit current contribution to the distribution system. This could result in increased short-circuit currents, potentially reaching damaging levels and resulting in protection desensitisation and a potential breach of protection coordination. Information and guidance on the protection of distribution systems are provided in NRS 034-1[27].

N.4.5.5 Voltage regulation and reactive power management

Generation in the distribution system must maintain the voltage limits during operations. The system has to be designed to avoid causing interference with the normal operation of the voltage regulation equipment. Where generation is variable in nature, the resultant voltage fluctuation may cause adverse effects on voltage regulation equipment. Voltage regulator controls may need to be modified or replaced when power is injected from the load side of the device. Furthermore, reactive power exchange at the point of common coupling has an impact on voltage regulation. Distributed generation output changes may occur more rapidly for circuit voltage controls, in which case voltage fluctuations of approximately one minute or less can occur.

N.4.5.6 Communications for Microgrids

When multiple generation, energy storage and load control devices are interconnected to form a microgrid, communication coordination is essential. Microgrid operation and fast recovery will significantly benefit from various communication-based control, protection and automation techniques.

Glossary, acronyms, abbreviations

Glossary

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:

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

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. NOTE: 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:

$$ADMD = ADMD(1\,000)$$

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.

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).

Living Standards Measure (LSM)
LSM levels have been developed by the South African Audience Research Foundation (SAARF) as part of the all media and product survey (AMPS) as a market segmentation tool. It segments households based on a range of appliances owned by the household. Households are categorised into 14 discrete levels making up LSM levels 1-10 (sub-ranges exist in LSM levels 7-10).

Maximum Demand
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).

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

Acronyms and abbreviations

ADMD	After Diversity Maximum Demand
COUE	Cost of Unserved Energy
CSP	Concentrated Solar Power
DSR	Demand side response
HD	High-density
kW	Kilowatt
kVA	Kilovolt-ampere
LD	Low-density
LSM	Living Standards Measure
LV	Low voltage
MV	Medium voltage
SAIDI	System Average Interruption Duration Index
SSEG	Small-scale embedded generation

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