Eskom	Standard	Technology

Title: **STANDARD TEMPLATE OF INFORMATION REQUIRED FOR THE PRODUCTION OF SUBSTATION DRAWINGS**

Unique Identifier: **240-68972746**

Alternative Reference Number: **N/A**

Area of Applicability: **Engineering**

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Date: 26/02/2021

This document is **STABILISED.** The technical content in this document is not expected to change because the document covers: *(Tick applicable motivation)*

1	A specific plant, project or solution	
2	A mature and stable technical area/technology	x
3	Established and accepted practices.	x

This letter is for multiple documents:

PCM Reference: **Design Substations**
SCOT Study Committee Number/Name: **Substations**

Eskom	**Standard**	**Technology**

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Content

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Tables

1. Introduction

A careful analysis of basic parameters establishing the purposes and design criteria for a substation needs to precede the detailed design. Much of this information can be found in the Grid Planning Report and documents that can be provided by other disciplines. In addition, circuit quantities, configurations, and ratings; system and equipment protective relay schemes; the necessity for specialized equipment (such as capacitor banks, current limiting reactors, and neutral earthing devices); details of surge protection equipment; and requirements for direct stroke protection must be considered. This document details what information is required as a basis for the design process.

2. Supporting clauses

2.1 Scope

This standard provides a listing of essential parameters required and documents where this information can be found in order to progress with the setting up of the design drawings. The document mainly applies to the design of Main Transmission Substations although many aspects can also be applied to distribution level substations.

2.1.1 Purpose

The intension of this document is to provide the substation designer a brief on the general parameters and important information that is required to be provided by other departments in order for the designer to formulate a proposed substation layout that will fulfil the requirements as described in the Grid Planning Report in the most optimally techno-economic manner.

2.1.2 Applicability

This document shall apply throughout Eskom Holdings Limited Divisions.

2.2 Normative/informative references

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

2.2.1 Normative

[1] ISO 9001 Quality Management Systems.

[2] Substation Layout Design Guide.

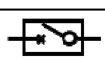
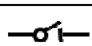
[3] South African Grid Code.

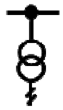
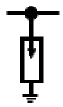
2.2.2 Informative

[4] NERSA Guidelines on Transmission Connection Charges.

2.3 Definitions

2.3.1 General

Definition	Description
	Circuit Breaker
	Isolator
	Current Transformer

Definition	Description
	Voltage Transformer
	Surge Arrester
'n – 1'	One line or transformer or reactive compensation device out of service (n-1), it shall be possible to supply the entire load under all credible system operating conditions

2.3.2 Disclosure classification

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

2.4 Abbreviations

Abbreviation	Description
BIL	Basic Insulation Level
HMI	Human-machine interface
HV	High Voltage
mH	Milli-henry
MV	Medium Voltage
MVA	Mega-volt-ampere
MVAr	Mega-var Reactive

2.5 Roles and responsibilities

Group lead engineers need to be fully briefed on the contents of this document. They will in turn be expected to instruct their direct reports in its use.

2.6 Process for monitoring

The tables at the end of the document are to become part of the design documentation.

2.7 Related/supporting documents

Substation Asset Specification

Substation User Requirement Specification

Transmission Planning Guide

Transmission Planning Report

3. Document content

3.1 Requirements

The Planning Report is a document prepared, signed and issued by the Grid Planning department. It provides a detailed account of the system studies that were conducted when considering a number of different load increment scenarios and possible solutions to meet the demand for power by requests received from possible clients and general incremental system growth that may come about from existing customers. The conclusions and recommendations section provided in the Planning Report summarises the most optimal option that is to be designed for. The following information is important:

- Single and three phase fault levels from fault level studies
- Whether feeders are in-feeds or out-feeds
- Feeder and transformer loading
- Transformer sizes and tertiary winding insulation level
- Requirement for fault current limiting reactors and sizes
- Line or busbar shunt reactor sizes and neutral insulation level
- Shunt and series capacitor bays and size
- Neutral End Reactor sizes
- Reliability and level of system security required
- Proposed line conductor
- Integration into the existing network

3.1.1 Single and Three Phase Fault Levels from Fault Level Studies

The single phase fault level is required for the design of the earthmat and for the specification of primary plant.

The three phase fault current is required for the calculations of the inter-phase short-circuit forces on the bay and busbar conductors in order to correctly specify equipment insulator strengths, and in particular, the bay and busbar support insulators.

3.1.2 Whether Feeders are In-feeds or Out-feeds

A stability study will provide information regarding the number of in-feed lines that can be lost before a stability problem arises. The Grid Code requires in-feeds with high power capacity to be selected onto separate zones of busbar as is the case for large power transformers. It is usual to select an in-feed, out-feed, power transformer combination onto one zone of busbar. The number of such groups will determine the number of zones of busbar required.

3.1.3 Feeder and Transformer Loading

The loading on circuits will provide direction on what conductor sizes should be employed in the respective bays. There are however minimum conductor sizes and phase bundle configurations for the higher voltages to mitigate corona.

3.1.4 Transformer Sizes and Tertiary Winding Insulation Level

The transformer size, again, has a bearing on the conductor sizes and phase bundle configurations. The conductors need to be rated for 120% of the transformer capacity.

3.1.5 Requirement for Fault Current Limiting Reactors and Sizes

In cases where additional transformation causes the fault level of the MV system to exceed equipment ratings, it is at times necessary to install fault current limiting reactors in series with the MV transformer bay as additional impedance. The size of the reactor would be determined by the planning engineer as part of the fault level studies conducted and would be found in the report.

3.1.6 Line or Busbar Shunt Reactor Sizes and Neutral Insulation Level

As part of the voltage stability studies conducted by the planning department, the requirement for line reactors for voltage control on transmission lines as a result of the Ferranti Effect on long lines would be highlighted.

In addition, there may be a requirement for voltage control on the busbar, hence busbar reactors would be specified. In some cases these busbar reactors need to be selectable to any of the lines, as is the case at 765kV. When used as a busbar reactor, the neutral end of the shunt reactor needs to be solidly earthed, bypassing the NER. Alternatively, used as a line reactor, the connection directly to earth needs to be removed, and earthing through the NER has to be effected. This can be achieved by using a bypass isolator connected in parallel with the NER.

Where reactors are installed with Neutral End Reactors, the shunt reactor neutral end will rise to a determined maximum value. This needs to be known to specify the neutral insulation. This can vary from 66kV through to 132kV.

3.1.7 Shunt and Series Capacitor Bays and Size

3.1.7.1 Shunt Capacitor

A shunt capacitor is installed where systems experience under-voltage conditions due to the demand for mega-vars by customers. Capacitors on the MV side of the transformers will provide these mega-vars without this being transformed through the transformers which would otherwise unnecessarily take up transformer capacity.

The capacity of the shunt capacitor will provide the means of determining the circuit conductor size and bundle configuration required. Harmonic studies are required to determine whether or not the capacitor bank should be a filter or could remain purely as a pure capacitor. The footprint of the bank is required to ensure enough space allocated on the terrace to accommodate it.

In the event of multiple capacitor banks, it is advantageous to so locate the banks to connect onto different zones of busbar in the same manner as transformers. This will ensure that if a zone of busbar is lost from service due to a fault, no more than one capacitor in lost from service, which may otherwise result in under-voltage conditions again.

3.1.7.2 Series Capacitor

A series capacitor is installed where a lines thermal capacity limit is way above its uncompensated economic loading value. Essentially the series capacitor compensates for the series inductance of the line as a result of the magnetic field set up around the phase bundle conductors. It effectively reduces the inductive reactance and increases the power transfer capacity of the line. The line may be compensated up to around 70% provided its thermal limit is not exceeded without series resonance occurring. However, whenever series capacitors are installed, sub-synchronous resonance (SSR) studies need to be conducted to find out if this phenomenon will occur.

Since the transfer capacity of the line is increased, the bay conductors need to be checked to ensure that they are adequately sized. In addition the equipment ratings need to be checked in terms of nominal and short-circuit capacity.

3.1.8 Neutral End Reactor Sizes

Neutral end reactor sizing is carried out by the planning department in order to determine the size of the NER required to maximise the line auto-reclosure success rate. The sizing is done in terms of milli-henries (mH) as well as the insulation level (kV) since it is to be connected to the shunt reactor neutral. The insulation level is also required for specifying the surge arrester which is connected at this point. The surge arrester is usually a high energy arrester.

3.1.9 Reliability and Level of System Security Required

This is related to paragraph 4.2 where the security of supply is at stake. At power stations for example, multiple feeders that terminate at the same destination or same general area are located such that selection onto busbars with will result in they will be positioned at least two circuit breakers apart. This is necessary to negate the impact of double zone (adjacent zones) faults causing multiple lines to the same destination being lost from service. This philosophy also applies to important main transmission substations which end up being important nodes in the system, e.g. Hydra Substation.

3.1.10 Proposed Line Conductor

The size of the line conductor will determine the feeder bay conductor size that should be used in order to match the capacity. This will in turn lead to the selection of the most appropriate clamps to be employed in the feeder bay.

3.1.11 Integration into the Existing Network

The Planning Report will provide information on how integration of the new feeder bays will be effected into the existing network, providing the destinations of the lines concerned. This will help with the implementation of paragraphs 3.1.2 and 3.1.9. This will also give some idea of the required orientation of the bays to accommodate the direction of approach of the transmission lines on both the HV and MV sides of the substation or power station HV yard.

3.2 Grid Code Compliance

The work carried out by Grid Planning is based on Grid Code requirements pertaining to the network. However, the Grid Code also has requirements relating to bay switching and the positioning of circuits for the various voltage levels. It is important that these requirements are taken into account when deciding on layout for a new substations or the addition of new bays at existing substations.

3.3 Site Selection, Geotechnical Report and Contour Plan for New Substation

The Planning Report will indicate the general area where substation should be located so as to be integrated into the existing network. For this a sketch is usually provided in the planning report. The geotechnical specialist then proceeds to select a number of sites for evaluation purposes, taking into account the size of the proposed substation and the direction of approach of the HV and MV lines.

The Geotechnical Report will provide the geotechnical specialist information regarding the suitability of a given site for a substation. The condition of the subsoil will provide information on its load bearing capability to support large items of equipment such as heavy steelwork structures, power transformers and reactors, and thus indicate whether or not a platform can be successfully constructed and how it should be constructed.

Once a single site is chosen, a detailed geotechnical assessment is done and the platform design parameters set. The design is based on a contour site plan which is a drawing produced by referencing a Key Plan on a Contour Plan to provide a best fit solution. Hence a detailed survey of the area is carried out and the electronic data supplied to the Civil Engineering department for them to generate the contour lines.

Soil resistivity measurements are made for the design of the earthmat and earthing system.

3.4 Project Charge Number

A charge number needs to be provided by the project manager assigned to the project so that time worked on the project can be captured from the inception of the project. It should be ensured that the charge number does work.

3.5 Basic Insulation Level (BIL) in Terms of Lightning Impulse Withstand (LIWL) and Switching Impulse Withstand (SIWL)

A transient study is required to determine the transient over-voltage (TOV) level that will occur on a transmission line due to either lightning or due to switching. This value is important in order to specify the BIL of all the HV and MV primary plant installed in a substation. The BIL for equipment is generally set at the tendering state, however, it is important to check the TOVs generated particularly on long lines so that mitigating measures may be implemented if these turn out to be very high.

3.6 Pollution Assessment Report

A pollution assessment of the site needs to be carried out so as to determine the insulation creepage level (mm/kV) required for successful operation of outdoor air insulated equipment. This value is important when requesting electrical equipment with porcelain or polymeric insulators as well as to determine the number of insulator discs required in an insulator string if glass disc insulators are used.

Protective Services Report for Security Level

When establishing a new substation, a report is required from protective services who will assess the location from a security point of view. This will determine the type of barrier and electrified fencing system that will be required around the substation. This activity is normally covered by the civil engineering section.

3.7 Substation User Requirement Specification (SURS)

The SURS will provide the following information:

- Single and three phase fault levels
- HV and MV voltage levels
- Number of equipped, spare and future feeders to be provided for, for each voltage level
- Number of equipped, spare and future transformer bays to be provided for
- Transformer sizes and voltage ratio
- Requirement for fault current limiting reactors and sizes
- Number of equipped, spare and future line and shunt reactor bays to be provided for
- Line or busbar shunt reactor sizes and voltage

The above together with the preceding information will assist in determining the most optimal layout for the station so as to accommodate all equipped, unequipped (spare) and future equipment bays.

3.8 Telecommunications Input

This input is necessary for the positioning of power line carrier equipment on the appropriate phases in a feeder bay if it is required, viz. the position of the line traps at the terminal ends of the line if they are indeed required. Lines that are 20km or shorter are usually equipped with current differential protection, viz. an optical fibre system. In this case, no line traps are required.

3.9 Land and Rights, and Line Design Input

Lands and Rights are involved in setting up the proposed transmission line corridors, setting up the process for the Environmental Impact Assessment (EIA) and negotiate with land owners to secure the line servitudes and land required to construct the substations. At this time, the geotechnical specialist will get involved in substation site selection. The sites will be selected bearing in mind the substation footprint and the direction of approach of the transmission lines.

Line conductor sizes and bundle configuration needs to be known so as to match this with the appropriate bay conductor sizes.

3.10 Sizing of Neutral End Reactor

See 3.1.8.

3.11 Sizing of Fault Current Limiting Reactor

See 3.1.5.

3.12 Busbar Cross Flow Studies

The flow of current on the busbar systems needs to be investigated in order to determine the appropriate conductor configuration required not only for the immediate application, but also taking into account possible future growth and expansion. The Planning Report provides load flow studies for a number of scenarios for the selected option. It is important to consider all of these, particularly the worst case contingencies to ensure that no section of busbar is overloaded.

3.13 Protection Requirements

Once the optimal layout of the station has been determined showing the end state of the substation, the protection department will determine all of the control panels required to fully the substation and the rest of the associated lines for faults and disturbances that may occur. There may be a request from the protection department to make a few changes to the Station Electric Diagram in order to achieve certain goals. Usually the changes are small such as the addition of a set of current or voltage transformers, providing generally accepted substation design principles are followed, negating the need for large scale changes.

The positioning of the control and telecommunications panels in accordance with the end state of the substation will determine the size of the control room which, together with the air conditioning requirements is employed by the civil engineering department in the design of the control room as part of the whole control building.

The protection department are required to furnish the current transformer buszone ratios. This is based on the HV and MV system fault levels that they would require.

3.14 Control Requirements

Some of the control requirements are integral to the protection requirements. In addition an HMI interface is required which generally takes the form of a computer and monitor which used to be housed in a separate room called the HMI room. However, these requirements are now accommodated in the control room.

In moving towards a SMART substation, there may be a requirement to motorise isolators at voltages of 132kV and downward. Motorised isolators are a standard requirement at 220kV and above.

3.15 Measurements and Metering

Measurements and metering panels are required to be installed in the control room. These requirements would be supplied with the protection and control requirements and will be part of the control room panel layout supplied by the secondary plant discipline.

Current transformers are supplied with metering cores whose ratios are set at the tendering stage. These are multi-ratio cores with ratios ranging from 200/1 up to 3200/1. These combinations should accommodate all circuit load current requirements, however, it makes for good engineering practice that the circuit maximum system current supplied by the load flows be checked against the CT ratios to ensure that the appropriate ratio is available to accommodate the current.

3.16 Battery Requirements

The dc systems department will determine the voltage and ampere-hour rating of the battery system (usually a dual battery system) for the HV and MV equipment motor drives where these are applicable. This together with the telecommunications battery and battery room washing requirements will be used by the civil engineering department for the design of the battery room.

3.17 Building Requirements

In addition to the control room and battery room, it is normal to include the following into the overall control building:

- Office
- Kitchen
- Male and female ablutions

3.18 Electrical Clearances

Integral in the design process it is essential to take note of electrical clearances between live parts of different phases, and between phase and earth. In addition, working clearances need to be observed. These clearances are all provided in the Substation Design Guide.

3.19 Power Equipment Oil Capacity

The oil capacity of the transformer is required for the determination of the capacity of the oil holding dam which is required to direct oil spills to a containment area via the oil drainage system that is required as part of the civil design. The oil dam is designed to accommodate 120% of the oil volume of the largest transformer or reactor installed at that site. This to allow for the accumulation of storm water drained from the power equipment bund areas.

3.20 Auto-reclosing of Circuit Breakers

Feeders at voltages of 220 kV and above are usually equipped with 3 mechanism circuit breakers for single pole auto-reclosure. Such circuit breakers are also installed on reactors and transformers for zero point tripping in conjunction with the installation of a relay for controlled tripping of each of the breaker poles.

Transformers do not have auto-reclosing, but rather equipped for three pole tripping.

For details on single and three mechanism circuit breakers, see document 240-xxxxxxxx titled “Standard for Choice of Single and Three Mechanism Circuit Breakers”

3.21 Requesting Equipment

Virtually all the parameters required for the requesting of primary plant is available from the information supplied from ensuring all the above is dealt with. These comprise inter alia the following:

- Nominal load current
- Single and three phase fault level
- System voltage
- Battery voltage

- BIL
- Requirement for single or three pole tripping
- Requirement for auto-reclosure
- Requirement for power line carrier or optical fibre, or both
- The tables that follow provide a summary of basic information that is necessary for various drawings. They apply to each voltage level within a substation that will be installed.

Table 1: Feeder Circuit Worst Case Contingency Loadings (Feeding into Busbar: -ve, Feeding out of Busbar: +ve)

Feeder 1 (MVA)		Feeder 2 (MVA)		Feeder 3 (MVA)		Feeder 4 (MVA)		Feeder 5 (MVA)	
Feeder 1 (A)		Feeder 2 (A)		Feeder 3 (A)		Feeder 4 (A)		Feeder 5 (A)	

Table 2: Proposed Feeder Bay Conductors

Feeder 1 (Line)		Feeder 2 (Line)		Feeder 3 (Line)		Feeder 4 (Line)		Feeder 5 (Line)	
Feeder 1 (Bay)		Feeder 2 (Bay)		Feeder 3 (Bay)		Feeder 4 (Bay)		Feeder 5 (Bay)	

Table 3: Feeder Telecommunications Requirements

Feeder 1 (PLC/OPGW)		Feeder 2 (PLC/OPGW)		Feeder 3 (PLC/OPGW)		Feeder 4 (PLC/OPGW)		Feeder 5 (PLC/OPGW)	

Table 4: Transformer Circuit Loadings (Feeding into Busbar: -ve, Feeding out of Busbar: +ve)

Transformer 1 (MVA)		Transformer 2 (MVA)		Transformer 3 (MVA)		Transformer 4 (MVA)			
Transformer 1 (A)		Transformer 2 (A)		Transformer 3 (A)		Transformer 4 (A)			
Transformer 1 (A) x 120%		Transformer 2 (A) x 120%		Transformer 3 (A) x 120%		Transformer 4 (A) x 120%			

Table 5: Proposed Transformer Bay Conductors

Trfr 1 (Bay)		Trfr 2 (Bay)		Trfr 3 (Bay)		Trfr 4 (Bay)		Trfr 5 (Bay)	

Table 6: Line Reactor Circuit Loadings (Feeding out of Busbar: +ve)

Feeder 1 (MVAr)		Feeder 2 (MVAr)		Feeder 3 (MVAr)		Feeder 4 (MVAr)		Feeder 5 (MVAr)	
Feeder 1 (A)		Feeder 2 (A)		Feeder 3 (A)		Feeder 4 (A)		Feeder 5 (A)	
Neutral BIL (kV)		Neutral BIL (kV)		Neutral BIL (kV)		Neutral BIL (kV)		Neutral BIL (kV)	
NER(mH)		NER(mH)		NER(mH)		NER(mH)		NER(mH)	

Table 7: Proposed Line Reactor Bay Conductors

Feeder 1 (Bay)		Feeder 2 (Bay)		Feeder 3 (Bay)		Feeder 4 (Bay)		Feeder 5 (Bay)	
Busbar Rx 1 (MVAr)		Busbar Rx 2 (MVAr)							
Busbar Rx 1 (A)		Busbar Rx 2 (A)							
Neutral BIL (kV)		Neutral BIL (kV)							
NER(mH)		NER(mH)							

Table 8: Busbar Reactor Circuit Loadings (Feeding out of Busbar: +ve)

Feeder 1 (Bay)		Feeder 2 (Bay)		Feeder 3 (Bay)		Feeder 4 (Bay)		Feeder 5 (Bay)	

Table 9: Proposed Busbar Reactor Bay Conductors

Feeder 1 Cap (MVAr)		Feeder 2 Cap (MVAr)		Feeder 3 Cap (MVAr)		Feeder 4 Cap (MVAr)		Feeder 5 Cap (MVAr)	
Feeder 1 Cap (A)		Feeder 2 Cap (A)		Feeder 3 Cap (A)		Feeder 4 Cap (A)		Feeder 5 Cap (A)	
Feeder 1 Cap (MVAr)		Feeder 2 Cap (MVAr)		Feeder 3 Cap (MVAr)		Feeder 4 Cap (MVAr)		Feeder 5 Cap (MVAr)	

Table 10: Proposed Series Capacitor Bank Bay Conductors

Feeder 1 (Bay)		Feeder 2 (Bay)		Feeder 3 (Bay)		Feeder 4 (Bay)		Feeder 5 (Bay)	

Table 11: Shunt Capacitor Bank Circuit Loadings (Feeding out of Busbar: +ve)

Capacitor 1 (MVAr)		Capacitor 2 (MVAr)		Capacitor 3 (MVAr)					
Capacitor 1 (A)		Capacitor 2 (A)		Capacitor 3 (A)					

Table 12: Proposed Shunt Capacitor Bank Bay Conductors

Capacitor 1 (Bay)		Capacitor 2 (Bay)		Capacitor 3 (Bay)		Capacitor 4 (Bay)		Capacitor 5 (Bay)	

Table 13: Transformers Tertiary Winding Circuit Loadings (Feeding out of Busbar: +ve)

Transformer 1 (MVA)		Transformer 2 (MVA)		Transformer 3 (MVA)		Transformer 4 (MVA)			
Transformer 1 (A)		Transformer 2 (A)		Transformer 3 (A)		Transformer 4 (A)			
Transformer 1 (A) x 120%		Transformer 2 (A) x 120%		Transformer 3 (A) x 120%		Transformer 4 (A) x 120%			

Table 14: Proposed Transformer Tertiary Conductors

Transformer 1 (Bay)		Transformer 2 (Bay)		Transformer 3 (Bay)		Transformer 4 (Bay)		Transformer 5 (Bay)	

Table 15: Voltage 3 Fault Current Limiting Reactors

Transformer 1 (mH)		Transformer 2 (mH)		Transformer 3 (mH)		Transformer 4 (mH)			

4. Authorization

This document has been seen and accepted by:

Name and surname	Designation
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5. Revisions

Date	Rev	Compiler	Remarks
Oct 2015	1	AJS Groenewald	First Issue.

6. Development team

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

- Abre le Roux Technology Group East London
- Braam Groenewald Technology Group Johannesburg
- Enderani Naicker Technology Group Johannesburg
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7. Acknowledgements

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