

Title: **STANDARD FOR
IMPLEMENTATION OF
SUBSTATION LAYOUTS FOR
TRANSMISSION SUBSTATIONS**

Unique Identifier: **240-109644476**

Alternative Reference Number: **240-57130114**

Area of Applicability: **Engineering**

Documentation Type: **Standard**

Revision: **1**

Total Pages: **28**

Next Review Date: **February 2021**

Disclosure Classification: **Controlled
Disclosure**

Compiled by



Braam Groenewald

Corporate Specialist-
Substations

Date: 27-01-2016

Approved by



Theunus Marais

Chief Engineer-Substations

Date: 27/01/2016

Authorized by



Phineas Tlhatlhetji

Senior Manager-Substation
Engineering

Date: 28/01/2016

Supported by SCOT/SC



Phineas Tlhatlhetji

SCOT/SC Chairperson

Date: 28/01/2016

Content

	Page
Executive Summary.....	4
1. Introduction.....	6
2. Supporting clauses	6
2.1 Scope	6
2.1.1 Purpose.....	6
2.1.2 Applicability	6
2.2 Normative/informative references	6
2.2.1 Normative.....	7
2.2.2 Informative	7
2.3 Definitions.....	7
2.3.1 General	7
2.3.2 Disclosure classification.....	8
2.4 Abbreviations.....	8
2.5 Roles and responsibilities	9
2.6 Process for monitoring	9
2.7 Related/supporting documents	9
3. Document content	9
3.1 Double busbar characteristics.....	9
3.2 Double busbar with bypass characteristics.....	12
3.2.1 Operation of bypass facility.....	15
3.3 Double busbar with transfer characteristics	15
3.3.1 Operation of transfer facility.....	17
3.4 Breaker-and-a-half characteristics	17
3.5 Power station high voltage yard	19
3.6 Rules for application.....	20
3.6.1 Main transmission substation (MTS) layout.....	20
3.6.2 Power station high voltage yard layout	24
4. Authorization.....	26
5. Revisions	26
6. Development team	26
7. Acknowledgements	27
Annex A – Configuration evaluation criteria [7]	28

Figures

Figure 1: Double busbar	10
Figure 2: Double busbar (with sectionalizing bays).....	10
Figure 3: Double busbar running split.....	11
Figure 4: Double busbar with bypass	12
Figure 5: Double busbar with bypass (with sectionalizing bay).....	13
Figure 6: Double busbar running split.....	14
Figure 7: Line 2 on bypass	15

Figure 8: Double busbar with transfer	16
Figure 9: Line 2 on transfer	17
Figure 10: Breaker-and-a-half	18
Figure 11: Power station HV yard.....	20
Figure 12: Use of breaker-and-a-half in both HV yards (all diameter circuits in opposite directions)	21
Figure 13: Use of breaker-and-a-half in both HV yards (not all diameter circuits in opposite directions)	21
Figure 14: Use of breaker-and-a-half together with double busbar selection with bypass or transfer	22
Figure 15: Use of breaker-and-a-half at power stations – double bus double breaker for generators.....	24
Figure 16: Schematic controlled closing sequence	25
Figure A.1: A: Evaluation criteria with matching score for service security.....	28
Figure A.2: A: Evaluation criteria with matching score for availability during maintenance of CBs and DSs.....	28
Figure A.3: A: Evaluation criteria with matching score for flexibility	28

Tables

Table 1: Evaluation criteria for double busbar configuration	11
Table 2: Evaluation criteria for double busbar with bypass configuration	14
Table 3: Evaluation criteria for double busbar with transfer configuration	16
Table 4: Evaluation criteria for breaker-and-a-half configuration	19

Executive Summary

Substations are a key and integral part of electrical power transmission network. Depending on the function of the substation there can be a great variety of different circuit configurations available.

Whenever new substations are planned or existing substations are extended, refurbished or replaced, a decision needs to be made whether to continue with existing circuit configurations or possibly change the circuit configuration philosophy of the substation.

Substations, that were built some 30 years or more ago, were designed when the characteristics and the design of high voltage apparatus were quite different from today's equipment. Circuit Breakers (CB) needed frequent maintenance and the main function of circuit configurations was therefore to enable access to CBs by surrounding them with isolators (IS). This is still the basis of most substations today.

Modern circuit breakers have a recommended maintenance interval of 15 years or more, while for air insulated switchgear (AIS) the isolator can have a substantially shorter maintenance interval, especially for locations exposed to pollution, e.g. industrial, salt, sand etc. The disconnecting function for maintenance purposes is still needed today but is more related to maintenance of non-switchgear switching equipment, e.g. power transformers, feeder circuits etc. in the substation. Disconnection may also be required for operational purposes, for example to limit short circuit currents in substations in meshed networks with large power infeeds.

Circuit configurations of high voltage substations are strongly influenced by many factors such as operational requirements, security standards, availability, maintainability, the need for sectionalizing, control and protection systems and regulations.

The development of switchgear with progressively longer maintenance intervals, based on a "sealed for life" design concept, the maintainability emphasis changes the substation design purpose. At the same time today's society is getting progressively more dependent on electric power supply for all its functions. This results in less tolerance towards quality of supply issues and black-outs, which will require designers to put more emphasis on high security (i.e. fault tolerance) and availability requirements for substations.

The basic purpose of a chosen circuit configuration is to facilitate the operational functions of a substation inside an electrical network. In the past, maintainability and accessibility of high voltage equipment was very important due to the requirements for frequent maintenance. Different types of circuit breaker design such as oil-filled breakers, air-blast breakers and also the different types of operating mechanisms required regular maintenance with short intervals. These requirements meant that various configurations and arrangements of substations were developed to isolate the circuit breaker and current transformer in a complete bay for maintenance while ensuring availability of supply on adjacent equipment. Isolators were required to deal with safety requirements and provide physical isolation during long term maintenance activities.

The developments in the design of high voltage devices and new switchgear components using different design principles with higher reliability or integrated functions mean that the reliable and efficient circuit configurations of the past may not be necessary and may result in onerous life-cycle-cost requirements for utilities.

In recent years, environmental requirement aspects have become more relevant and important, and have to be considered when planning high voltage substations. However, minimising the impact on the environment of materials and practices used in a substation needs to be balanced with the requirement for equipment to be able to withstand severe environmental and climatic conditions.

Eskom has developed their own version of national Health, Safety and Environment (HSE) regulations. These are driven by personnel safety and country-specific statutory regulations to ensure substations are accessible and maintenance operations are safe.

The location where power will be generated is another factor influencing the configuration of a substation. Wind power is expanding all around South Africa.

The objective of this standard is to elaborate on technical guidelines and to provide information for the selection and comparison of Circuit Configurations to support the selection of an optimised solution with regard to the specific requirements, various locations and functional requirements.

There has been an introduction of breaker-and-a-half for 765kV in Eskom as well as certain 400kV substations. The question has been asked as to whether this configuration should be applied to all voltages or limited or applied where space is limited.

Added to this document are the requirements for the Transmission HV yard layout at power stations.

1. Introduction

Whenever new substations are planned or existing substations are extended, refurbished or replaced, the substation design engineer needs to decide whether to continue with existing classical circuit configurations and high voltage equipment or to apply innovative and compact high voltage apparatus and possibly change the circuit configuration philosophy of the substation.

The objective of this document is to provide technical guidelines and to provide information for the selection and comparison of Circuit Configurations to support the selection of an optimised solution with regard to the specific requirements.

2. Supporting clauses

2.1 Scope

The scope of this document is to develop criteria to provide high level guidance for evaluating and comparing circuit configurations and the variation that different applications have on the characteristics of these configurations. The assessment criteria can be applied to the double busbar, double busbar with bypass, double busbar selection with transfer and, breaker-and-a-half (BAH) circuit configurations and their applications.

The selection of an appropriate circuit configuration and its possible extension for a particular substation is an important initial step of the design of a substation. In developing criteria to aid in the selection of the most appropriate configuration the following performance factors are analysed and evaluated:

- Service security
- Availability during maintenance
- Operational flexibility.

This document therefore:

- Outlines the differences between the substation layouts double busbar (DBB), double busbar with bypass (DBBP), double busbar selection with transfer (DBT) and, breaker-and-a-half (BAH)
- Highlight the requirements from the grid
- Defines critical substation
- Defines conditions for use of DBB, DBBP, DBT and BAH
- Define the requirements for use of BAH at power stations.

2.1.1 Purpose

The purpose of this document is to provide the criteria for the selection of busbar arrangements.

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] Reliability of Substation Configurations (Daniel Nack, Iowa State University, 2005).
- [3] The South African Grid Code (Revision 8.0).

2.2.2 Informative

- [4] Definition of Eskom documents (32-9).
- [5] Eskom documentation management standard (32-644).
- [6] Operating manual of the Steering Committee of Technologies (474-65).
- [7] Circuit Configuration Optimization, Joint Working Group, B3/C1/C2.14

2.3 Definitions**2.3.1 General**

Definition	Description
Availability	The ability of an item to be in a state to perform a required function under given conditions at a given instant of time or over a given time interval, assuming that the required external resources are provided. The state of an item of being able to perform its required function.
Breaker-and-a-half	The breaker-and-a-half bus arrangement is relatively simple and consists of two main busbars, each normally energised. Between each of the main busbars are similarly arranged "bays" of three circuit breakers configured such that the two transmission lines or combination transmission line and transformer position share the centre circuit breaker (refer Figure 10 for diagram)
Critical substation	Refer to section 3.6.1.
Double busbar selection with bypass	A double (main and bypass) busbar arrangement consists of two independent busbars, both of which are normally energised. During normal operations, all transmission lines and transformers are electrically connected to one or the other busbar, with circuits being equally distributed over the busbars (refer to Figure 4 for diagram)
Double busbar selection with transfer	A triple (two main and transfer) busbar arrangement consists of three independent busbars, two of which are normally energised, while the transfer busbar is only energised when a feeder is on transfer. During normal operations, all transmission lines and transformers are electrically connected to one of the two main busbars, with circuits being equally distributed over the busbars (refer to Figure 8 for diagram)
Extra High Voltage (EHV)	The set of nominal voltage levels that are used in power systems for bulk transmission of electricity in the range $220\text{kV} < U_n \leq 400\text{kV}$. [SANS 1019]
High Voltage (HV)	The set of nominal voltage levels that are used in power systems for bulk transmission of electricity in the range $44\text{kV} < U_n \leq 220\text{kV}$. [SANS 1019]
Low Voltage (LV)	The set of nominal voltage levels that are used for the distribution of electricity and whose upper limit is generally accepted to be an a.c. voltage of 1,000V (or a d.c. voltage of 1,500V). [SANS 1019]

Definition	Description
Maintainability	The ability of an item under given conditions of use, to be retained in, or restored to, a state in which it can perform a required function, when maintenance is performed under given conditions and using stated procedures and resources
Medium Voltage (MV)	The set of nominal voltages that lie above low voltage and below high voltage in the range $1\text{kV} < U_n \leq 44\text{kV}$. [SANS 1019]
Operational flexibility	<p>The ability to split the substation, for the following reasons:</p> <p>To limit the consequences in case of a primary fault in the substation such as not losing both circuits feeding a supply point, e.g. two power transformers or a double overhead line, etc. can be connected to different busbars so that for a busbar fault or a feeder fault with following breaker failure only one of the feeders is lost. In these cases the two parts of the substation are usually electrically connected together in normal service, e.g. by a closed bus-coupler or bus-section CB, which will give the highest availability and best use of the busbar</p> <p>To limit the short circuit current. In that case bus coupler CB or bus section CB will be kept in the open position</p> <p>To prevent load current from exceeding the rated values of the busbars</p> <p>The ability to arrange the incoming and outgoing feeders to match system conditions.</p> <p>Note: The ability to arrange incoming and outgoing feeders can be done at two stages:</p>
Security	Ability of a substation configuration (primary and secondary) to operate in such a way that credible events do not give rise to loss of load, stresses of system components beyond their ratings, bus voltages or system frequency outside tolerances, instability, voltage collapse, or cascading
Transfer Bus Coupler	A circuit that connects an independent busbar (transfer busbar) to either of the two main busbars (BB 1 or BB 2).
Ultra High Voltage (UHV)	The set of nominal voltage levels that are used in power systems for bulk transmission of electricity in the range $U_n > 400\text{kV}$. [SANS 1019]

2.3.2 Disclosure classification

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

2.4 Abbreviations

Abbreviation	Description
BAH	Breaker and a half
BB	Busbar
CB	Circuit breaker
CoE	Centre of Excellence
CT	Current transformer
DBB	Double busbar selection
DBBP	Double busbar selection with bypass
DBDB	Double bus double breaker

ESKOM COPYRIGHT PROTECTED

Abbreviation	Description
DBT	Double busbar selection with transfer
GIS	Gas insulated switch gear
GM	General manager
HMI	Human Machine interface
HV	High voltage
kV	Kilovolt
MV	Medium voltage
MW	Mega watt
PDE	Power delivery engineering
PLC	Process logic controller
SCADA	Substation communication and data acquisition
SGM	Senior general manager
TXBC	Transfer bus coupler
VT	Voltage transformer

2.5 Roles and responsibilities

Substation Engineering shall utilise and implement the busbar selection criteria within this document.

2.6 Process for monitoring

The following design review teams shall evaluate and monitor the selection of busbar layouts:

- 1) Substation Design Review Team.
- 2) PTM&C Design Review Team.
- 3) Power Delivery Engineering Design Review Team.

2.7 Related/supporting documents

Not applicable.

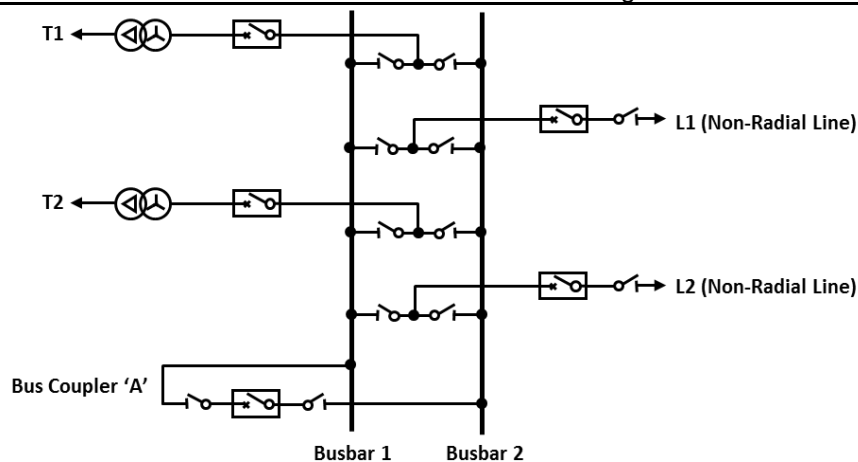
3. Document content

3.1 Double busbar characteristics

Definition: A Double busbar substation is a substation in which the lines and transformers are connected via two busbars by means of selectors, i.e. a double busbar with coupler bay in which the lines and transformers are connected to either of two busbars by means of selector isolators.

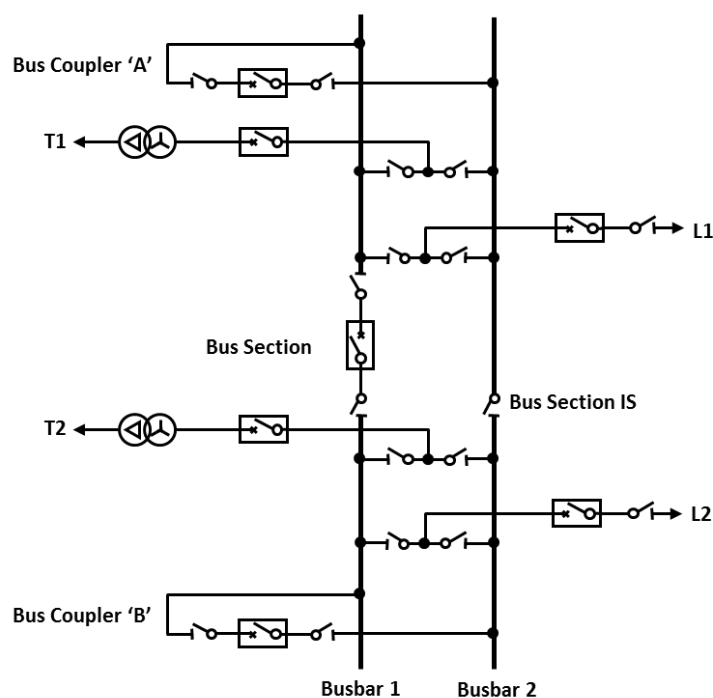
The double busbar arrangement is recommended for large substations where security of supply is important. These are particularly suitable for highly interconnected (meshed) power networks in which switching flexibility is important and multiple supply routes are available. They are also used for splitting networks, which are only connected in emergency cases.

The coupler circuit breaker allows the possibility of keeping half of the station in service following a fault on the busbar, a busbar isolator, or any feeder circuit breaker.

**Figure 1: Double busbar**

The configuration provides flexibility by allowing each circuit to be connected to either of the two busbars. It is also possible to move circuits from one busbar to the other while they are energised.

Additional flexibility can be provided by adding sectionalizer isolators and/or bus sections into each busbar as illustrated in Figure 2.

**Figure 2: Double busbar (with sectionalizing bays)**

Maintenance of all equipment in a circuit requires only a single circuit outage and an outage of one busbar at a time: it is possible to keep all other circuits in service by connecting them to the other busbar and by changing them from one busbar to the other as required to allow busbar isolator maintenance. The security provided by the double busbar configuration is however lost while the substation is in this situation.

The double busbar configuration also allows additional circuits to be added to the station without any need for outages on the existing circuits.

Service security:

- This configuration is based on two busbars which are connected together by a coupler bay i.e. a primary fault (with the exception of a fault on the coupler circuit breaker) will not cause the loss of the whole substation.
- A primary fault in one busbar where the coupler circuit breaker fails to open will cause the loss of the whole or part of the substation, depending on the number of zones in existence.

Availability during maintenance:

- Maintenance of any busbar isolator will require the outage of the circuit and of the relevant busbar. However the double busbar configuration allows all other circuits to remain in service by having them connected to the other busbar.
- The maintenance of coupler circuit breaker will cause the two busbars to be separated i.e. for this period the substation will have to operate as one or two single busbar substations.

Operational flexibility:

- The ability to split the substation into two single busbars with the opening of the coupler circuit breaker provides very good flexibility (see Figure 3). The addition of sectionalizer isolators and/or bus sections provides even more possibilities for circuit rearrangement as shown in Figure 2.

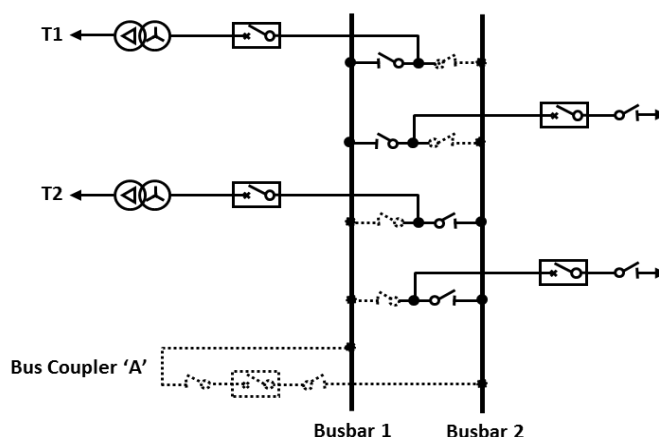


Figure 3: Double busbar running split

- The two busbar isolators on each circuit make it possible to decide at any time to which busbar the circuit is to be connected.
- Even with this level of flexibility the substation design engineer may still need to consider from the beginning where circuits are connected to the busbar, particularly when sectionalizer isolators are used.
- Splitting the substation into two single busbars or moving circuits from one busbar to another can all be carried out with the substation fully energised.

The evaluation criteria with the associated scores for this configuration are given below (with reference to annex A):

Table 1: Evaluation criteria for double busbar configuration

Criteria	Score
Service security	2
Availability during maintenance	4
Operational flexibility	5

ESKOM COPYRIGHT PROTECTED

3.2 Double busbar with bypass characteristics

Definition: A substation in which the lines and transformers are connected via two busbars by means of selectors where one of the main busbars which becomes the bypass busbar to which any circuit can be connected independently of its bay equipment (circuit-breaker, instrument transformer), the control of this circuit being ensured by another specific bay, a bus coupler, available for any of the line circuits. In other words, it is a substation in which the lines and transformers are connected to either of two busbars by means of selector isolators.

Note: This bypass busbar (see Figure 4) is counted as one of the busbars within a "double" busbar substation configuration.

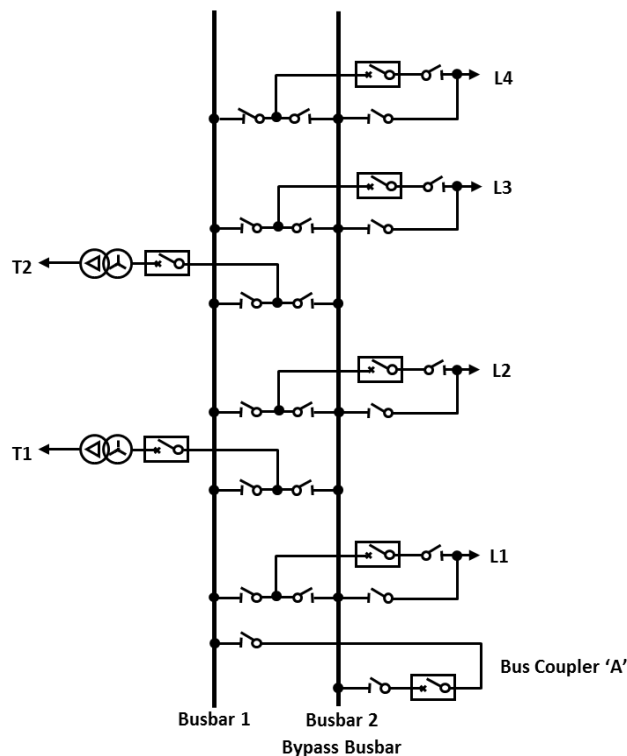


Figure 4: Double busbar with bypass

This arrangement has the same characteristics and functionality of the double busbar configuration but it is recommended for use when there is a requirement to keep circuits in service during maintenance or repair of the circuit breaker or the busbar isolators. A circuit outage is however still required for maintenance of the line and by-pass isolators.

Connection of a circuit to the bypass busbar requires that its protection be transferred to the bus coupler circuit breaker i.e. any fault on the circuit will result in the bus coupler circuit breaker being tripped.

Provision of this Bypass facility adds complexity to the design of the circuit protection and also to the design of the bus zone and circuit breaker failure protection systems.

Additional flexibility can be provided by adding sectionalizer isolators or bus sections into each busbar as illustrated in Figure 5.

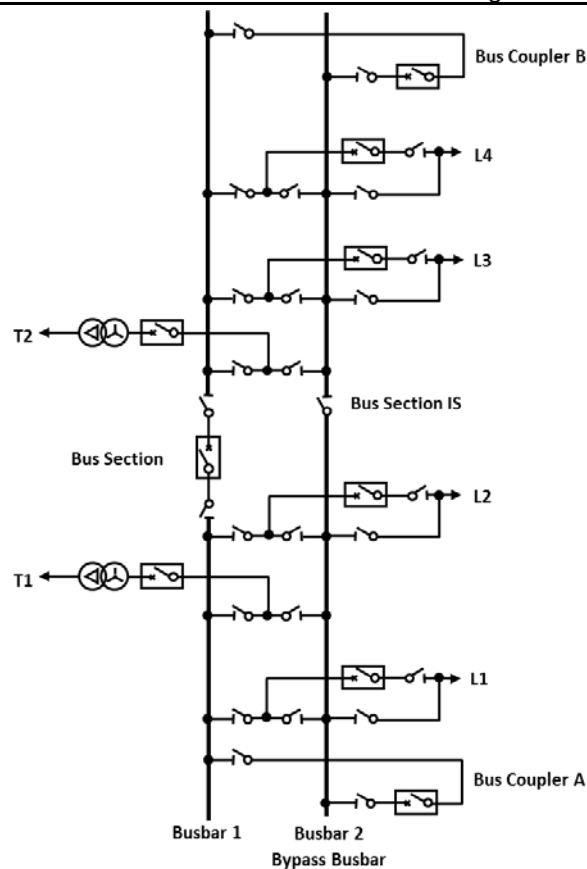


Figure 5: Double busbar with bypass (with sectionalizing bay)

Maintenance of all equipment in a circuit requires only a single circuit outage and an outage of one busbar at a time: it is possible to keep all other circuits in service by connecting them to the other busbar and by changing them from one busbar to the other as required to allow busbar isolator maintenance. The security provided by the double busbar configuration is however lost while the substation is in this situation.

The double busbar configuration also allows additional circuits to be added to the station without any need for outages on the existing circuits.

Service security:

- This configuration is based on two busbars which are connected together by at least one coupler bay such that a primary fault (with the exception of a fault on the coupler circuit breaker) will not cause the loss of the whole substation.
- A primary fault in one busbar where the coupler circuit breaker fails to open will cause the loss of the whole or part of the substation, depending on the number of zones in existence.

Availability during maintenance:

- Maintenance of any busbar isolator will require the outage of the circuit and of the relevant busbar. However the double busbar configuration allows all other circuits to remain in service connected to the other busbar.
- The maintenance of coupler circuit breaker will cause the two busbars to be separated i.e. for this period the substation will have to operate as one or two single busbar substations.

Operational flexibility:

- The ability to split the substation into two single busbars with the opening of the coupler circuit breaker as shown in Figure 6 provides very good flexibility. The addition of sectionalizer isolators and/or bus sections provides even more possibilities for circuit rearrangement.

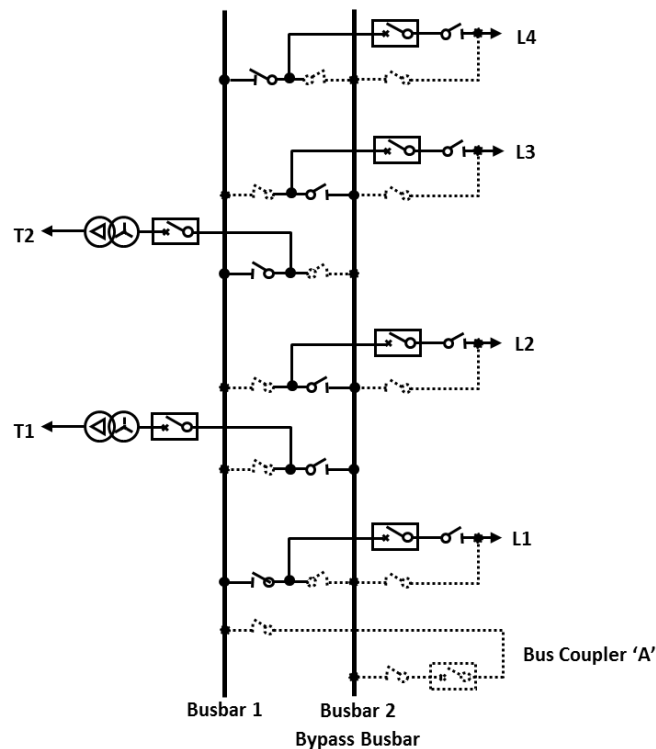


Figure 6: Double busbar running split

The two busbar isolators on each circuit make it possible to decide at any time to which busbar the circuit is to be connected.

Even with this level of flexibility the substation design engineer may still need to consider from the beginning where circuits are connected to the busbar, particularly when sectionalizer isolators and bus sections are used.

Splitting the substation into two single busbars or moving circuits from one busbar to another can all be carried out with the substation fully energised.

The evaluation criteria with the associated scores for this configuration are given below (with reference to annex A):

Table 2: Evaluation criteria for double busbar with bypass configuration

Criteria	Score
Service security	2
Availability during maintenance	6
Operational flexibility	5

3.2.1 Operation of bypass facility

Connection of a circuit to the bypass busbar requires that its protection be transferred to the bus coupler circuit breaker i.e. any fault on the circuit will result in the bus coupler circuit breaker being tripped. Busbar 2 is cleared by selecting all circuits onto busbar 1. Figure 7 illustrates how Line 2 is selected to Busbar 2 through the bypass isolator. All control of Line 2 is passed on to the bus coupler, Bus Coupler 'A'.

Provision of this bypass facility adds complexity to the design of the circuit protection and also to the design of the bus zone and circuit breaker failure protection systems.

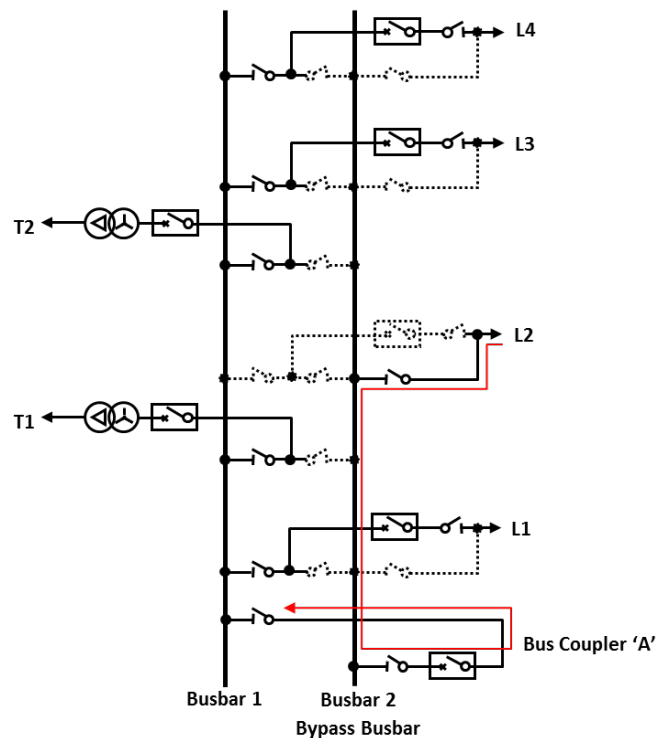


Figure 7: Line 2 on bypass

3.3 Double busbar with transfer characteristics

Definition: A back-up busbar to which any circuit can be connected independently of its bay equipment (circuit-breaker, instrument transformer), the control of this circuit being ensured by another specific bay, a transfer bus coupler (TXBC), available for any of the line circuits.

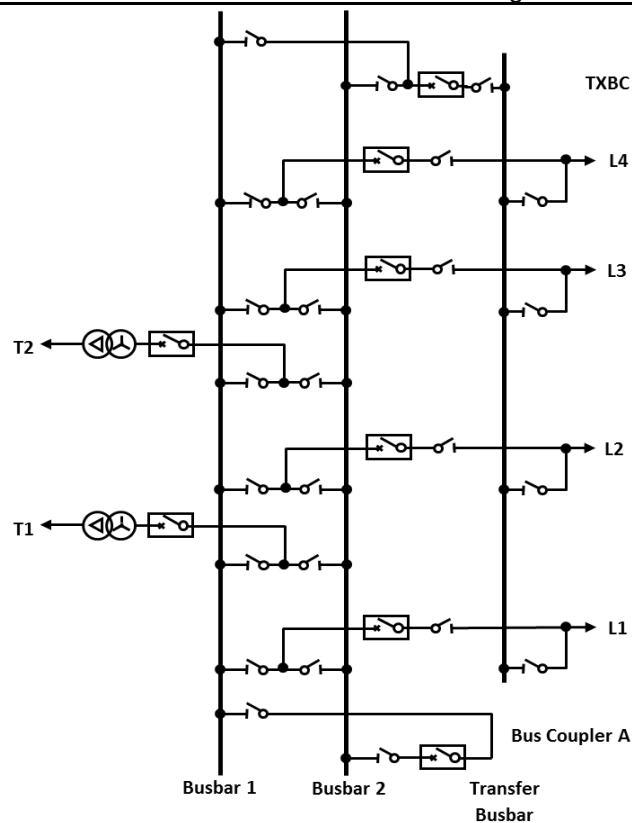
Note: This transfer busbar is generally not counted as one of the busbars within a "double" or "triple" busbar substation configuration.

This arrangement has the same characteristics and functionality of the double busbar with bypass configuration but it is recommended for use when there is a requirement to keep circuits connected to the two main busbars and in service during maintenance or repair of the circuit breaker or the busbar isolators. A circuit outage is however still required for maintenance of the line and transfer isolators.

Connection of a circuit to the transfer busbar requires that its protection be transferred to the transfer bus coupler circuit breaker i.e. any fault on the circuit will result in the transfer bus coupler circuit breaker being tripped.

Provision of this transfer facility adds complexity to the design of the circuit protection and also to the design of the bus zone and circuit breaker failure protection systems.

Similar to the double busbar with bypass configuration, this configuration also allows additional circuits to be added to the station without any need for outages on the existing circuits.

**Figure 8: Double busbar with transfer****Service security:**

- The normal operation of this configuration has to be considered with both main busbars connected together through the coupler and each circuit connected to one of the busbars. In this mode the configuration has the same level of service security as the double busbar with bypass configuration.

Availability during maintenance:

- Availability of circuits during maintenance is increased, compared to the double busbar configuration, as a circuit outage is only required for maintenance of the line and transfer isolator but also for instrument transformer maintenance.
- The rest of the characteristics are the same as double busbar with bypass.

Operational flexibility:

- The evaluation from the point of view of flexibility is the same as double busbar.

The evaluation criteria with the associated scores for this configuration are given below (with reference to annex A):

Table 3: Evaluation criteria for double busbar with transfer configuration

Criteria	Score
Service security	3
Availability during maintenance	6
Operational flexibility	5

3.3.1 Operation of transfer facility

Connection of a circuit to the transfer busbar requires that its protection be transferred to the transfer bus coupler circuit breaker i.e. any fault on the circuit will result in the transfer bus coupler circuit breaker being tripped. Busbars 1 and 2 remain in service. Figure 9 illustrates how Line 2 is selected to the transfer Busbar through the transfer isolator. All control of Line 2 is passed on to the transfer bus coupler, Bus Coupler (TXBC).

Provision of this transfer facility adds complexity to the design of the circuit protection and also to the design of the bus zone and circuit breaker failure protection systems.

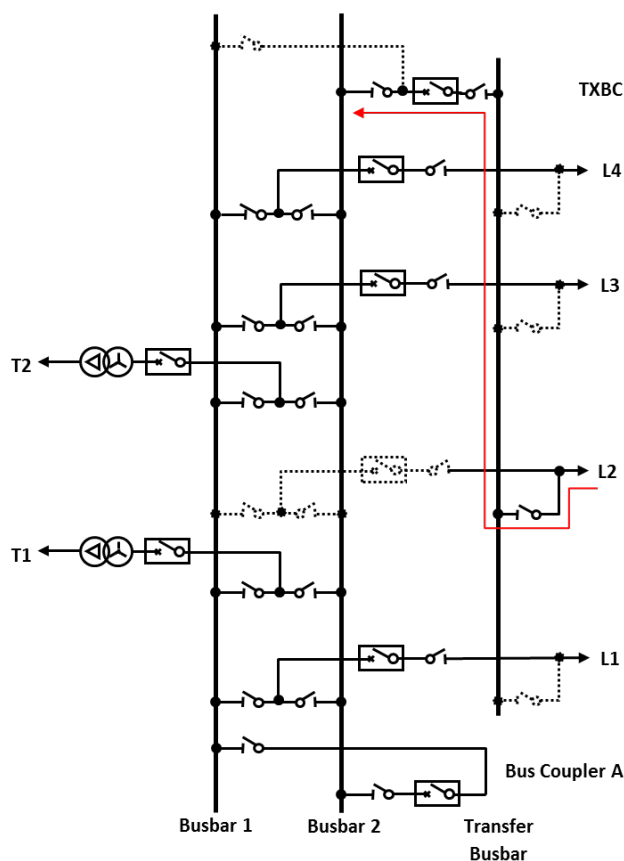


Figure 9: Line 2 on transfer

3.4 Breaker-and-a-half characteristics

Definition: A double busbar substation where, for two circuits, three circuit-breakers are connected in series between the two busbars, the circuits being connected on each side of the central circuit-breaker.

Note: Each connection between the two busbars is called a diameter.

The one-and-a-half circuit breaker (or “breaker-and-a-half”) arrangement is particularly suitable for substations handling large amounts of power, such as those associated with generating stations, and for networks which comprise mainly radial circuits with few mesh connections.

It should be noted that in order to cover all switching contingencies the circuit breakers and associated equipment should be capable of handling the combined load current of two circuits and an allowance for current transfer between the busbars. This is due to the fact that the breaker-and-a-half circuit configuration does not have any separate bus coupler circuits, since each diameter is acting as a bus coupler.

Circuit control and protection design is quite complex as each circuit protection must operate on two circuit breakers and the central circuit breaker is controlled by two circuit protection systems. Busbar-side breakers are only controlled by one circuit protection system plus the busbar protection.

However design of the bus zone and circuit breaker failure protection systems is simpler than the multiple busbar configurations with selector isolators as the systems do not need to select which circuit breakers to trip in response to a busbar fault or a circuit breaker fail situation.

The substation is normally operated with all circuit breakers closed.

No circuit outages are required during the installation of a new feeder.

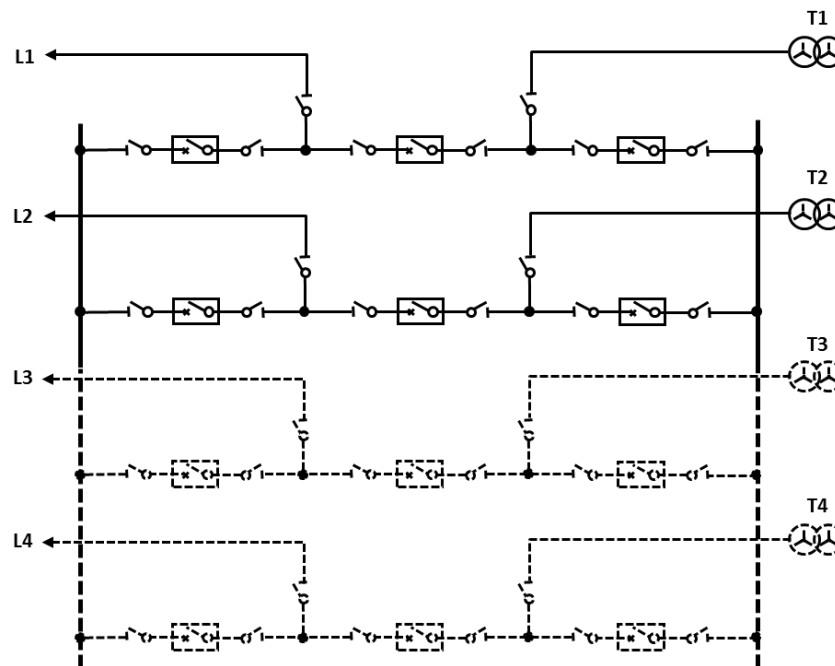


Figure 10: Breaker-and-a-half

Service security:

- This configuration uses two busbars. Each circuit is connected to the substation through two circuit breakers; the central (tie) circuit breaker is shared between two feeders while a busbar-side breaker is dedicated to one circuit.
- A primary fault will not cause the loss of the whole substation but only the loss of the faulted circuit or the loss of one busbar without the loss of any circuits.
- A fault on one of the central (tie) circuit breakers will result in the loss of two circuits.
- A primary fault when one circuit breaker fails to open will cause, as worst consequence, the loss of one other circuit but never the whole substation.

Availability during maintenance:

- Because there are two circuit breakers per circuit, it is possible to maintain any circuit breaker without any circuit outage.
- Maintenance of a busbar isolator requires a busbar outage but does not require an outage of any circuit. Maintenance of any of the other isolator will require an outage of a single circuit.

Operational flexibility:

- Various methods of splitting the substation are possible but each arrangement has some limitations. These methods include:
 - Opening all of the central (tie) circuit breakers: two single busbars will be obtained. However it is not possible to select which feeder is connected to each busbar.
 - Circuits can only be associated with the remote busbar by opening the adjoining busbar-side circuit breaker. However in this situation a fault on one of the circuits could result in both of the circuits on the diameter losing supply
 - Opening the two busbar-side circuit breakers of a diameter; in this situation the two circuits on a diameter remain connected together but separated from both busbars. This means that the substation can transfer power with both busbars out of service, which is unique for this scheme.
 - Any splitting of the substation can be carried out with the substation fully energised.

The evaluation criteria with the associated scores for this configuration are given below (with reference to annex A):

Table 4: Evaluation criteria for breaker-and-a-half configuration

Criteria	Score
Service security	5
Availability during maintenance	6
Operational flexibility	4

3.5 Power station high voltage yard

The main purpose of a Power Station High Voltage (HV) yard is to provide the means to export generated power to the power system and separate the Power Plant from the network if a fault occurs. Depending on the nature of the generator and criticality, additional circuits may be required to improve network security and ensure power is available during network disturbances.

A single line diagram of an HV yard connected to a Power Station is shown in Figure 11. Most of the Eskom power station HV yards have this configuration, or at least a variation of this. The two busbar system is known as a Main and Hospital Bus system. Generally, the Main busbar is divided up into as many zones with bus sections as there are generators. Each generator will have at least one feeder connected to it, with feeders to the same destination or same general area arranged at least two circuit breakers apart. The bus system loop is closed with the inclusion of bus couplers at the extreme ends of the busbar system.

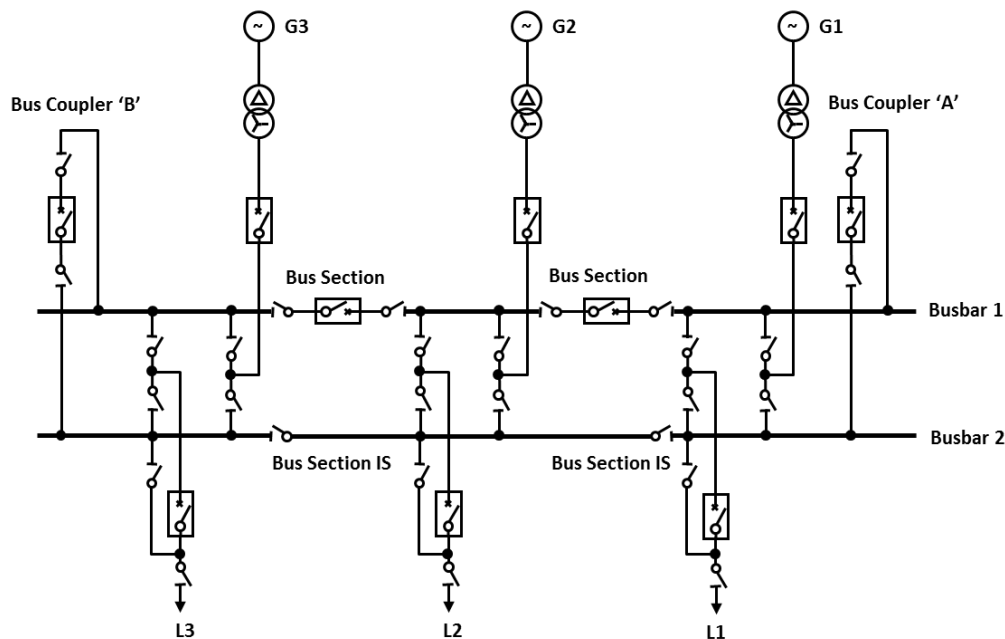


Figure 11: Power station HV yard

Service security

- This parameter is very important for this type of substation since the delivery of energy from the power plant to the grid has a high value.

Availability during maintenance

- This value will vary significantly depending on the type of generator (e.g. wind farms and nuclear will be very different). The substation maintenance can be coordinated to when Power Plants normally have yearly maintenance periods where substation material may be maintained.

Operational flexibility

- This is once again dependent on the generator configuration, however normally there is no need for rearrange feeders in this type of substation.

3.6 Rules for application

3.6.1 Main transmission substation (MTS) layout

The breaker-and-a-half (BAH) scheme is more reliable than double busbar with bypass or transfer (DBBP or DBT). This is by a factor of at least 90% (0.00301 for BAH compared to 0.0453 for a sectionalised busbar (DBBP or DBT) [1]). This refers to the overall probability of failure resulting in loss of supply with the two options.

These reliability figures do not include the possible operator error, however, it is considered easier to operate breaker-and-a-half as compared to double busbar with bypass or transfer.

An advantage of the breaker-and-a-half arrangement is that a busbar fault or operator error will result in the loss of the applicable busbar or a diameter and not a substantial portion of the substation. It is thus a more forgiving design for operator error than a double busbar with bypass or transfer.

In the case of Air Insulated Systems (AIS), the land footprint of the BAH is on the whole smaller than DBBP or DBT as long as the ratio of lines to transformers or reactors is less than around 1.5. It is, however, largely dependent on the coupling arrangement between the equipment yards and the direction of approach of lines terminating at the station. Generally speaking, feeders enter on the opposite side of the busbars to that of the transformer positions. A 1:1 match is better suited to a BAH arrangement.

ESKOM COPYRIGHT PROTECTED

Figure 12 illustrates an arrangement where both HV yards employ BAH. In this case the line to transformer ratio is 2,3. Here, however, the diameter circuits exit the yard in opposite directions, and all 3 transformers are next to each other, each transformer being banked with a feeder. Pairs of feeders exiting the station in opposite directions can be added at the ends of the busbar system as shown.

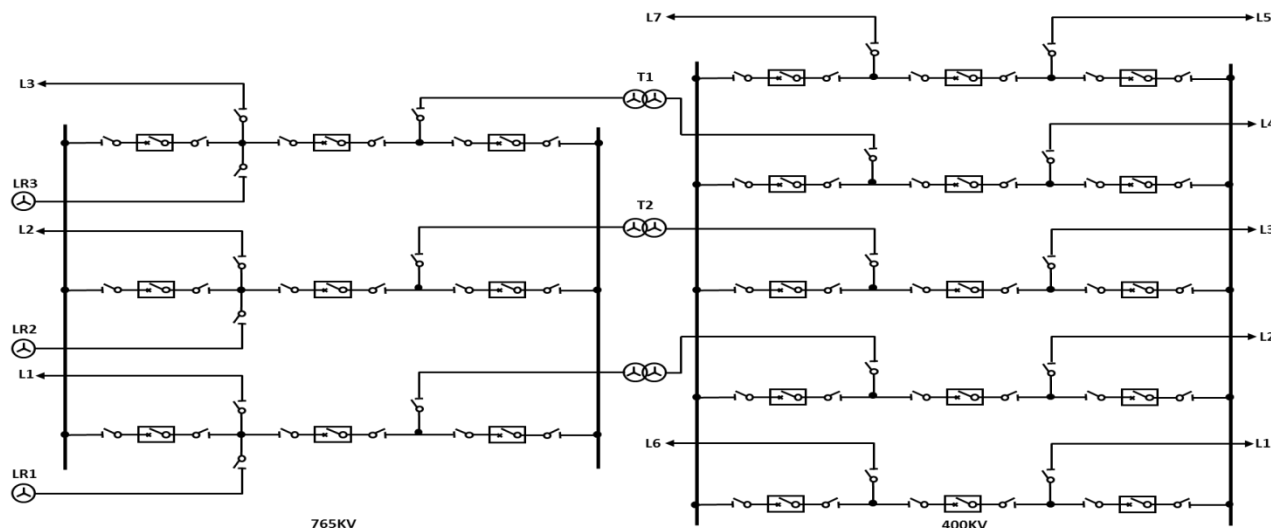


Figure 12: Use of breaker-and-a-half in both HV yards (all diameter circuits in opposite directions)

Where all the feeders exit the HV yard in the same direction, and that are opposite to the side that the transformers are located, the arrangement becomes somewhat more difficult to realise. Figure 13 shows the manner, in which this can be achieved, particularly where pairs of feeders are located on the same diameter, and are positioned between transformers. For a low profile tubular bus substation, the arrangement takes up two, at most 3 bay widths.

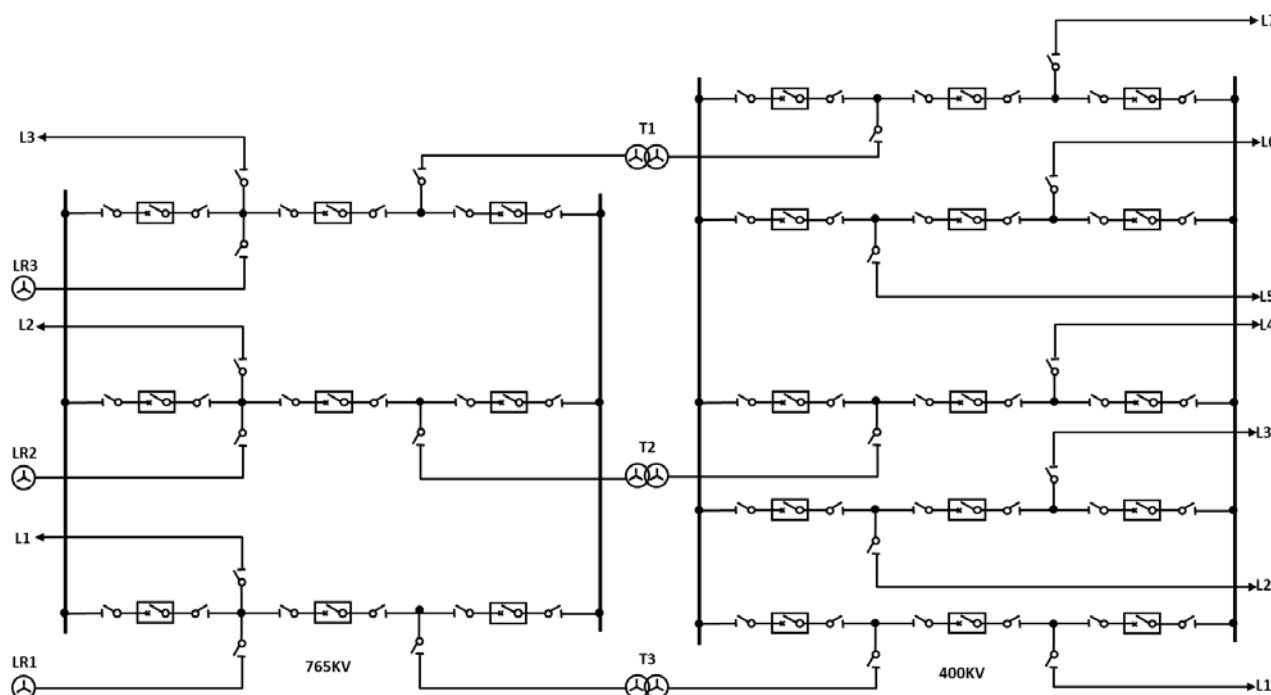


Figure 13: Use of breaker-and-a-half in both HV yards (not all diameter circuits in opposite directions)

AIS Transformation substations with voltages 400/132(88)kV generally start off with line to transformer ratios of 4:1. Figure 14 illustrates a typical minimum arrangement of 2 transformers and at least 8 feeder bays, not all feeders necessarily being equipped at the initial stage. Such stations are normally limited to 4 x 500MVA transformers so that fault levels do not exceed the rupturing capacities of the HV primary plant. Normally, up to 16 x HV feeder bays would be built. With such a large number of feeders, particularly if overhead lines are connected to all of these bays, it becomes impractical to use BAH on the HV side as the land required becomes excessive. Spare bays have to be introduced in any event in order to space feeder terminal towers, and therefore negates the advantage of fewer bays. If cable connections are to be used, then there is an advantage of space saving.

For the foregoing reasons, DBB or DBBP will always be employed at voltages ≤ 132 kV unless it can be justified as being a strategically important yard such as a feeding system to a nuclear station. All existing and future nuclear stations are and will be located at the coast so that the HV yard would in all likelihood be gas insulated switchgear (GIS). GIS lends itself very well to the BAH philosophy. The arrangement in Figure 14 can easily be realised.

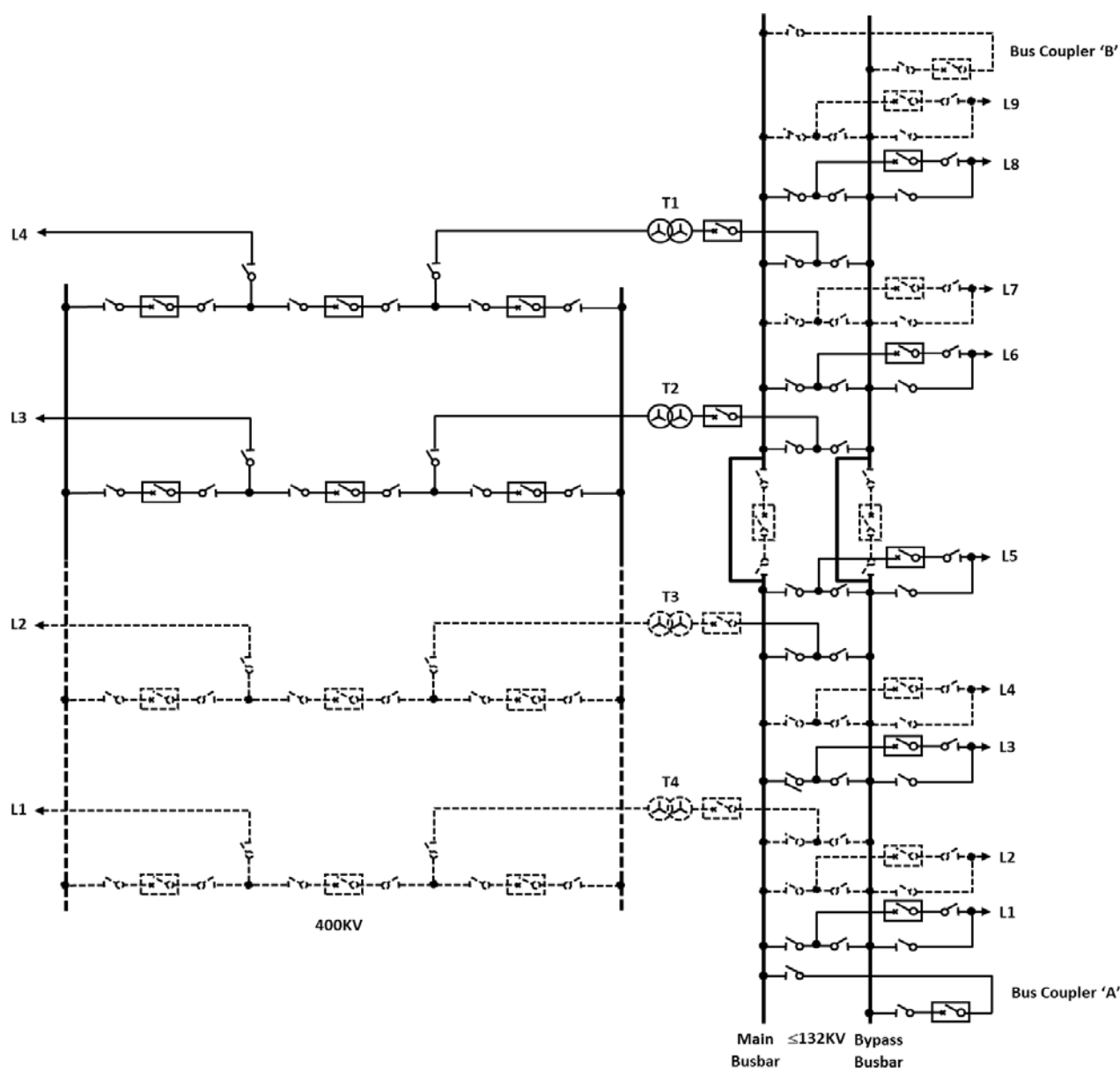


Figure 14: Use of breaker-and-a-half together with double busbar selection with bypass or transfer

ESKOM COPYRIGHT PROTECTED

The drawback of BAH is that protection is more complicated and has not been in service in Eskom for very long. One breaker needs to operate for faults from more than one direction. The relatively greater complexity of the BAH protection schemes comes at a higher cost as compared to DBBP or DBT, thus requires greater justification for implementation of BAH to yards of voltages $\leq 132\text{kV}$.

Overall, the cost of BAH is around 10-20% more than DBBP or DBT depending on number of diameters and land cost.

Most of the 765kV lines require line reactors and cannot be operated without them. It is essential that there be a means to link busbar reactors to any line that may have a defective reactor so as to be able to energise it. In order to achieve this, an additional reactor transfer busbar is required which makes the operation of relinking relatively simple.

The application of BAH will be done in accordance with the following:

- 1) All critical substations at voltages including and above 275kV to use breaker-and-half configuration where critical is defined as:
 - All National Key Points as defined in terms of the National Key Points Act, 1980 (e.g. nuclear facilities).
 - Power stations with total output equal to or exceeding 1000MW.
 - Stations forming part of a major power corridor where a major power corridor is defined as a transfer route that if interrupted will cause major disruption to a Province or number of metropolitan areas, e.g. Cape corridor.
 - Stations supplying sensitive load equal to or greater than 500MW (e.g. aluminium smelters) where an interruption can cause major economic losses.
 - Stations supplying load equal to or exceeding 500MW where an interruption would create significant health and safety risks, e.g. deep level gold and platinum mines.
 - Stations supplying a total local load equal to or exceeding 500MW (to be determined from the final expected loading of the substation).
 - All 765kV substations
- 2) For substations that are not critical, where the size is limited and double bus with bypass or transfer cannot be used, breaker-and-a-half is to be considered. This is irrespective of the voltage (excludes Distribution division substations).
- 3) Fully established 132kV yards of Transmission substations normally have a feeder bay to transformer number far in excess of 1.5 and therefore double bus with bypass should be considered. In special cases where this ratio is lower than 1.5, breaker-and-a half can be considered if the HV yard is breaker-and-a half, and it can be motivated as being a critical station in terms of 1 above.

Breaker-and-a-half stations will also be equipped with one or more local substation human machine interfaces (HMI) that incorporate interlocking that is integrated with both the distribution and national control centre SCADA systems.

The HMI interlocking schemes will include "Objective State Control" at both the bay and substation levels.

Note that there may be occasions such as brownfields (existing substations) where the BAH may prove not suitable due to risk (as a result of construction constraints, operations etc.). In these cases the BAH option needs to be investigated thoroughly and if found not suitable rejected with reasons. The relevant technical governance committee would normally take this decision however in cases of disagreement SGM Engineering will make the final decision.

3.6.2 Power station high voltage yard layout

The following are relevant to power station high voltage yards:

- All generator bay connections shall be double busbar double breaker (dedicated diameter). Figure 15 illustrates this in terms of a conventional 6-pack power station. This is also applicable to nuclear power stations with fewer generating units but, which generally have large generators (900MW+).

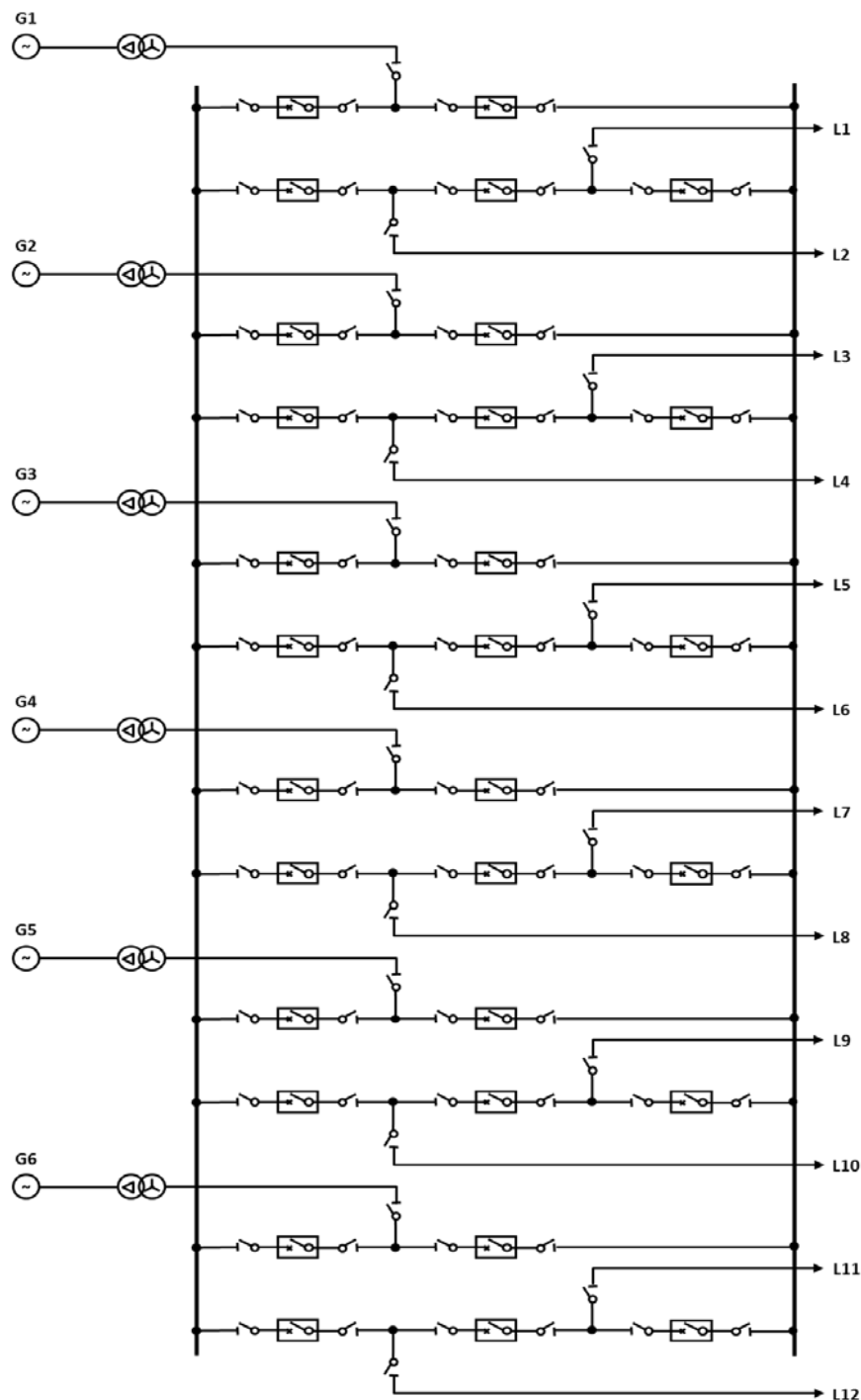


Figure 15: Use of breaker-and-a-half at power stations – double bus double breaker for generators

ESKOM COPYRIGHT PROTECTED

- All the busbar voltage levels at a particular generation station shall have the same busbar layout arrangement
- The standard location of the HV yards shall be as close as possible to the power station
- The operating accountability (open and close commands) of the breakers and isolators within this dedicated generator diameter shall be with Generation (as per service level agreements at the different stations)
- Overlapping current transformers (CTs) shall be installed on both bay 1 and bay 2 breakers of the generator bays
- The following voltage transformers (VTs - 3 phases) shall be directly connected to the generation equipment (synchronizer(s))
 - Busbar 1 VT
 - Busbar 2 VT
 - VTs between the bay 1 and bay 2 breakers (connector VTs)
- Coupling transformers and station transformers shall not be on the same diameter
- Generation shall own the synchronizing equipment for both breakers. The synchronizing equipment shall be located within the generation equipment room

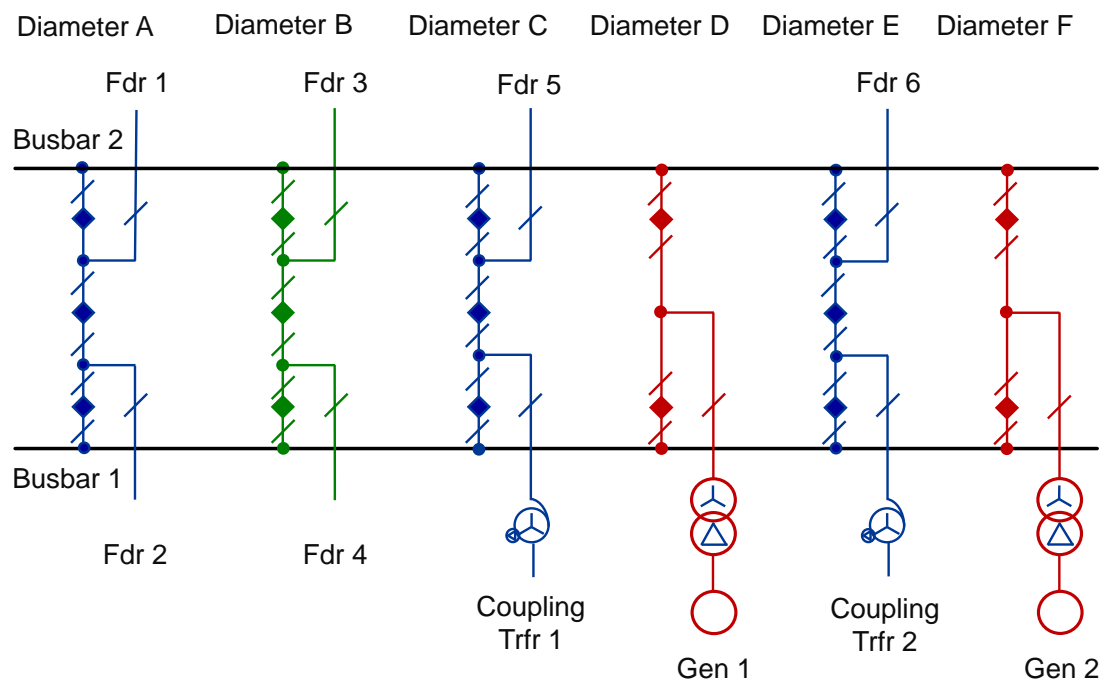


Figure 16: Schematic controlled closing sequence

Generation preference for both the BAH and DBBP or DBT busbar layout arrangements

The following preferences are identified:

- HV yard generator bay breakers to have a single operating mechanism
- HV yard generator bay isolators to have a single operating mechanism.

4. Authorization

This document has been seen and accepted by:

Name and surname	Designation
Rob Stephen	Master Specialist – Power Delivery Engineering
Phineas Tlhatlhetji	Senior Manager-Substation Design
Thys Bower	Corporate Specialist – Protection
Richard McCurrach	Senior Manager – PTM&C
Leslie Naidoo	Senior Manager – Grid Planning
Bheki Ntshangase	Senior Manager – HV Plant
Gavin Hurford	Corporate Specialist – System Operations
Leon Kotze	Senior Consultant - Protection
Paul Davel	Chief Engineer – System Operations
Ruaan Nel	Senior Engineer – Lines Engineering Services
Sanjay Narain	Chief Engineer
Dawie Senekal	Senior Technologist – Substations (Civil)
Derrick Delly	Chief Engineer - Substations
Enderani Naicker	Chief Engineer - Substations
Ian Hill	Senior Technologist - Substations
Mark Pepper	Chief Engineer - Substations
Rukesh Ramnarain	Chief Engineer - Substations
Sipho Zulu	Chief Engineer - Substations
Nkuli Pompei	Senior Technologist - Substations
Chico Ramgovind	Chief Engineer
Ian Worthington	Chief Engineer – Engineering Southern Grid
Johan Pieterse	Chief Engineer
Kooben Munsamy	Chief Engineer
Lester Geldenhuis	Chief Engineer – Western Grid
Paul Grobler	Chief Engineer
Ravi Govender	Chief Engineer – Transmission East Grid

5. Revisions

Date	Rev	Compiler	Remarks
Feb 2016	1	AJS Groenewald	First issue as 240-57130114

6. Development team

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

ESKOM COPYRIGHT PROTECTED

When downloaded from the WEB, this document is uncontrolled and the responsibility rests with the user to ensure it is in line with the authorized version on the WEB.

- Rob Stephen
- Thys Bower
- Braam Groenewald
- Theunus Marais

7. Acknowledgements

- M. Viljoen
- R. van Heerden
- G. Hurford
- M. van Niekerk
- P. Barnard

Annex A – Configuration evaluation criteria [7]**Figure A.1: A: Evaluation criteria with matching score for service security**

Score	Possible consequences to the network because of a primary fault	Possible consequences to the network because of a primary fault when breaker fails to open
1	Possible loss of the whole substation	Loss of the whole substation
2	Loss of one or more feeders but not the whole substation	Loss of more than one feeder or the whole substation
3	Loss of one or more feeders but not the whole substation	Loss of more than one feeder but not the whole substation
4	Loss of one feeder	Loss of one feeder and always one feeder more but not the whole substation
5	Loss of none or one feeder	Loss of one feeder and possibly one feeder more but not the whole substation
6	Loss of none or one feeder	Loss of one feeder

Figure A.2: A: Evaluation criteria with matching score for availability during maintenance of CBs and DSs

Score	Maintenance of	Consequence
1	Any busbar disconnector	Outage of whole substation
2	Sectionaliser Disconnecter	Outage of whole substation
3	Any busbar or sectionaliser disconnector	Outage of half the substation
4	Any busbar disconnector	Outage of one busbar, remaining objects in service on the same busbar
5	Any busbar disconnector	Outage of one busbar, remaining objects in double busbar configuration
6	Any busbar disconnector	Remaining circuits in service Open ring Split up of the substation
	Circuit breaker	Split-up of the substation and all circuits in service
7	Any busbar disconnector	Outage of one busbar, all objects in service on the same busbar
	Circuit breaker	All circuits remain in service

Figure A.3: A: Evaluation criteria with matching score for flexibility

Score	Definition
1	Not possible to split
2	Non-energized split (DS only), no flexibility
3	Energized split (with CB), No flexibility
4	Energized split (with CB), Low flexibility
5	Energized split (with CB), High flexibility, switching with DS
6	Energized split (with CB), High flexibility, switching with CB's Highest flexibility, switching with DS