Eskom	**Practice Note**	**Technology**

Title: **PRACTICE NOTE FOR IMPLEMENTATION OF SUBSTATION LAYOUTS FOR TRANSMISSION SUBSTATIONS**

Unique Identifier:	**240-57130114**
Alternative Reference Number:	**<n/a>**
Area of Applicability:	**Engineering**
Documentation Type:	**Practice Note**
Revision:	**1**
Total Pages:	**13**
Next Review Date:	**April 2019**
Disclosure Classification:	**Controlled Disclosure**

Compiled by	**Approved by**	**Authorized by**
Rob Stephen	**Prince Moyo**	**Willy Majola**
Master Specialist Group Technology	**Power Delivery Engineering GM**	**Group Technology**
Date:03 APRIL 2014	Date: 4/04/2014	Date: 4/4/2014
		Supported by SCOT/SC
		Rob Stephen
		SCOT Chairman
		Date:03 APRIL 2014

PCM Reference: **<xxxxxx>**

SCOT Study Committee Number/Name: **<Number or name>**

Content

Page

1. Introduction 3
2. Supporting clauses 3
   2.1 Scope 3
      2.1.1 Purpose 3
      2.1.2 Applicability 3
   2.2 Normative/informative references 3
      2.2.1 Normative 3
      2.2.2 Informative 3
   2.3 Definitions 4
      2.3.1 General 4
      2.3.2 Disclosure classification 4
   2.4 Abbreviations 4
   2.5 Roles and responsibilities 5
   2.6 Process for monitoring 5
   2.7 Related/supporting documents 5
3. Busbar layout characteristics 5
   3.1 Characteristics of breaker and a half 5
      3.1.1 Current use of Breaker and a half 6
   3.2 Characteristics of double bus with transfer 6
4. Rules for application of substation layout 6
   4.1 Decision of meeting held on 12 November 2012 6
   4.2 Decision of meeting with generation held on 30 August 2013 6
      4.2.1 Following is the requirements that were agreed upon at this meeting: 7
      4.2.2 Generation preference for both the CB&1/2 and DBB busbar layout arrangements 7
   4.3 Rules for application of substation layout 8
5. Authorization 8
6. Revisions 9
7. Development team 9
8. Acknowledgements 9

Annex A - Grid, System Operations, requirements, opinions and comments from Substation CoE 10

Annex B - Diagrams of different substation layouts 13

Figures

Figure 1: Number of Buszone and Busstrip Incidents over last ten years 10

Figure 2: Causes of bz/bs incidents in 2011 jan to june. 11

1. Introduction

There has been an introduction of breaker and 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.

This report investigates the issue and provides a summary of the requirements from Transmission Operating unit and the agreement from the meeting held on 12 November 2012.

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

2. Supporting clauses

2.1 Scope

This document:

- Outlines the differences between the substation layouts breaker and a half (BAH) and double bus with bypass (DB);
- Highlight the requirements from the grid;
- Describes decisions taken at meeting on 12 November 2012;
- Defines critical substation;
- Defines conditions for use of BAH and DB; and,
- 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 (selection criteria for breaker-and-a-half and double busbar).

2.1.2 Applicability

This Practice Note is mandatory with immediate effect on all projects that has not progressed to detail design stage. This document will be adapted from time to time as required.

2.2 Normative/informative references

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).

2.3 Definitions

2.3.1 General

Definition	Description
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 Annex B for diagram)
Double bus 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 Annex B for diagram)
Critical substation	Refer section 4.3

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
DB	Double bus with bypass
CoE	Centre of Excellence
CT	Current transformer
GIS	Gas insulated switch gear
GM	General manager
HMI	Human Machine interface
HV	High voltage
kV	Kilovolt
MV	Medium voltage

Abbreviation	Description
MW	Mega watt
PDE	Power delivery engineering
PLC	Process logic controller
SCADA	Substation communication and data acquisition
SGM	Senior general manager
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. Busbar layout characteristics

3.1 Characteristics of breaker and a half

The breaker and half scheme are more reliable than double busbar with transfer. This is by a factor of at least 70% (0.003 for breaker and a half compared to 0.005 to double bus double breaker [1]). This refers to the overall probability of failure resulting in loss of supply with the two options.

The reliability figures do not include the possible operator error but again it is considered easier to operate breaker and a half compared to double bus with transfer.

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

The land footprint of the breaker and half is smaller than double bus with transfer as long as the ratio of lines to transformers or reactors is less than 1.5 (this is an opinion but could be a lower ratio). With 132kV substations in 400/132kV arrangement, it is not feasible to use breaker and a half as the land required will be too much. The ratio of 132kV lines to transformers is normally in excess of 3.

The drawback of breaker and a half is that protection is more complicated and has not been in service in Eskom. One breaker need to operate for faults from more than one direction.

Another issue is the ability to link a reactor to other lines which is required by system operations at 400kV and 765kV. In order to achieve this, an additional reactor transfer busbar is required which makes operation very complicated.

The cost of breaker and a half is around 10-20% more than double bus with transfer depending on number of diameters and land cost.

To maintain an isolator on each side of the centre breaker requires two circuits to be de-energised.

3.1.1 Current use of Breaker and a half

The breaker and a half configuration were used at 765kV due to the fact that the size of the standard configuration is excessive and not feasible for operation. GIS solution is extremely expensive (R90m per bay when market was last tested). The AIS option was only valid with a breaker and half configuration due to the low ratio of transformers to line bays. It has to be used with the reactor transfer bus which is complicated to operate. The increased reliability was not used as a primary motivator for the selection of the layout.

In order to simplify operations the standpoint was taken that the 400kV substation as part of the 765/400 kV station should also be breaker and a half. Again this was possible due to the low ratio of transformers to line bays. Protection is still and issue and has not been tried and tested.

For Acacia the breaker and a half option was used as it can be accommodated with transformer and feeders being placed back to back. It also solves the problem with the two Philippi feeders which only have double busbar selection (no bypass available due to the physical positioning of the feeders at the end of the 400kV busbars). The design is however ‘n-1’ compliant. Alternative GIS could have been used

3.2 Characteristics of double bus with transfer

The current double bus with transfer is commonly used at all voltages within Transmission substations (excluding MV).

The performance of the layout has proved reliable at all voltages including 765kV. Issues relating to Koeberg have not been as a result of the busbar layout but due to equipment or secondary plant issues.

Operators are familiar with the layout, protection is tried and tested.

It can accommodate the linking of reactors to other line feeders.

Drawbacks include the impact of operator error when transferring items to a busbar. The design is not forgiving for and error and can result in a busbar fault.

4. Rules for application of substation layout

4.1 Decision of meeting held on 12 November 2012

The following is an extract from the minutes of the meeting held on 12 November 2012 between Grid (Western), Technology (SGM Engineering, Acting GM PDE, GM Master Specialist, Substation CoE, PTM&C)

“Discussion was held as to the needs from the Grids, the faults that have occurred and the benefits and drawbacks of each of the layouts. **It was agreed that important substations defined as level 1 will have breaker and a half layout and that it is possible to have different layouts for different voltage yards in the same substation.”**

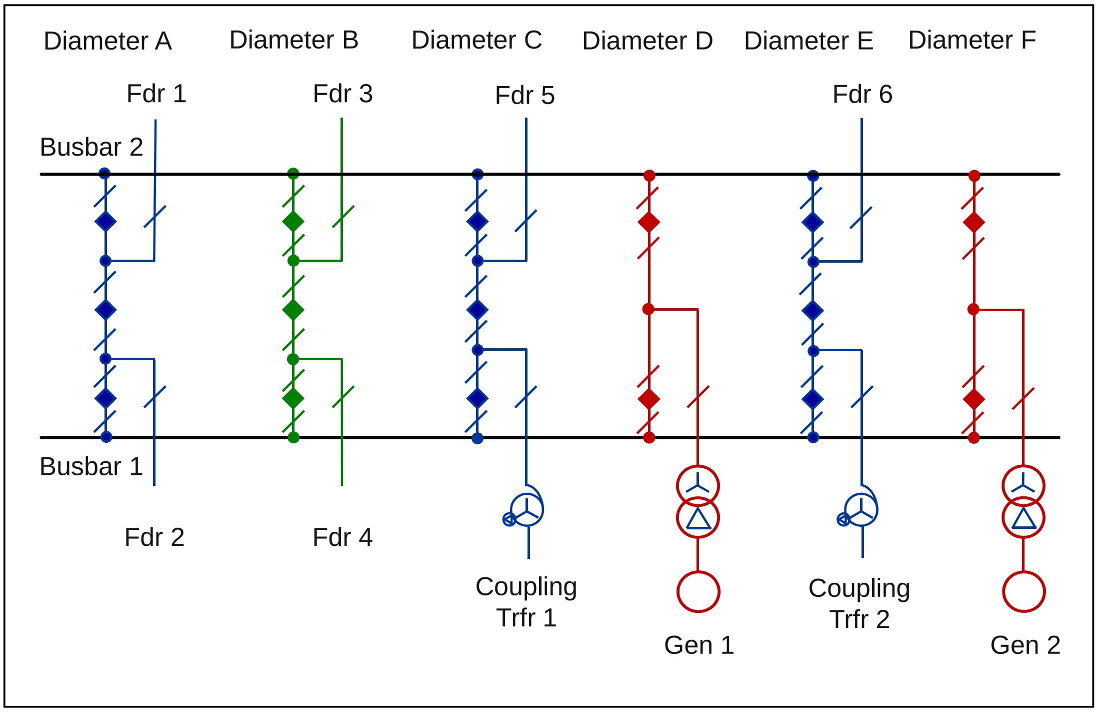
Subsequently the term “Level 1” was altered to “critical”

4.2 Decision of meeting with generation held on 30 August 2013

The following is an extract from the minutes of the meeting held on 30 August 2013 between PTM&C (Protection), PDE Substation engineering, PTM Koeberg, Generation Plant Engineering and PEIC (Generation).

4.2.1 Following is the requirements that were agreed upon at this meeting:

- All generator bay connections shall be double breaker double busbar (dedicated diameter);
- 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 a 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 CTs shall be installed on both bay 1 and bay 2 breakers;
- The following VTs (3 phase) shall be directly connected to the generation equipment (synchroniser(s));
  - o Busbar 1 VT;
  - o Busbar 2 VT; and,
  - o VT between the bay 1 and bay 2 breakers (connector VT).
- The coupling transformer and station transformer shall not be on the same diameter; and,
- Generation shall own the synchronising equipment for both breakers. The synchronising equipment shall be located within the generation equipment room.



4.2.2 Generation preference for both the CB&1/2 and DBB busbar layout arrangements

The following preferences were identified:

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

4.3 Rules for application of substation layout

1) All critical substations at voltages including and above 275kV to use breaker and a half where critical is defined as:

   a) All National Key Points as defined in terms of the National Key Points Act, 1980 (e.g. nuclear facilities).

   b) Power stations with total output equal to or exceeding 1000MW.

   c) 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).

   d) Stations supplying sensitive load equal to or greater than 500MW (e.g. aluminium smelters) where an interruption can cause major economic losses.

   e) 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).

   f) Stations supplying a total local load equal to or exceeding 500MW (to be determined from the final expected loading of the substation).

   g) All 765kV substations

2) For substations that are not critical, where the size is limited and double bus with bypass cannot be used, breaker and a half is to be considered. This is irrespective of the voltage (excludes Distribution division substations).

3) 132kV yards of Transmission substations normally have a feeder bay to transformer number 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.

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) or 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 and if found not suitable rejected with reasons. The relevant Governance committee would normally take this decision, however, in cases of disagreement SGM engineering will make the final decision.

5. Authorization

This document has been seen and accepted by:

Name and surname	Designation
W Majola	Group Technology
P Moyo	Power Delivery Engineering GM
R Stephen	Master Specialist Group Technology

6. Revisions

Date	Rev.	Compiler	Remarks
April 2014	1	T. Bower	Generation requirements added
Nov 2012		R Stephen	Final Document for Authorisation Final draft after input from SO, Grids, Technology

7. Development team

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

- R. Stephen
- B. Groenewald
- R. McCurrach
- E. Lechtman
- M. van Rensburg
- W. Majola
- P. Moyo
- T. Bower
- E. Naicker
- M. Viljoen

8. Acknowledgements

- R. van Heerden
- G. Hurford
- R. Candy
- J. Botma
- M. van Niekerk
- P. Barnard
- M. Visser

Annex A- Grid, System Operations, requirements, opinions and comments from Substation CoE

Requirements were presented as follows (comments from B. Groenewald in brackets)

- Circuits must not be interrupted for busbar faults (This is normally catered for in the double busbar selection option by designing for 'n-1' and the inclusion of sections and couplers)
- Double busbar faults must not interrupt continuity of supply (Not always possible with 1½ CB arrangement, an in-feed needs to be complimented with an out-feed, e.g. a feeder onto a transformer. This can become a very tricky exercise. The system topology is also very dynamic, sometimes changing the feeding direction of a feeder).
- A bus strip protection must only interrupt the circuits linked to the breaker that failed (If the buszone protection operates correctly, then this should be the result in any event)
- Must be able to maintain all breakers without interrupting circuits (including transformers, capacitors and reactors) (Currently a shortcoming of the double busbar selection with bypass/transfer. Only feeder breakers can be maintained without interruption. In the case of transformers, this is accommodated by having 'n-1' in transformers.)
- All CTs and VTs must be inboard (Not all CTs and VTs inboard even with 1½ CB arrangement. Circuits will have to be switched out for the maintenance of some CTs and VTs).
- Use technologies that will eliminate PLCs (The total elimination of PLC may not be possible, particularly for long lines. One would have to introduce repeater stations along long lines which itself becomes a problem due to them being sited at remote locations).
- Motorise all isolators 765 - 132kV
- HMI to control all equipment 765 – 132kV
- Maximum circuit unavailability during refurbishing <5 days

Issues upon which the requirements are based are as follows:

- There has been an increase in buszone and busstrip incidents over the past few years.

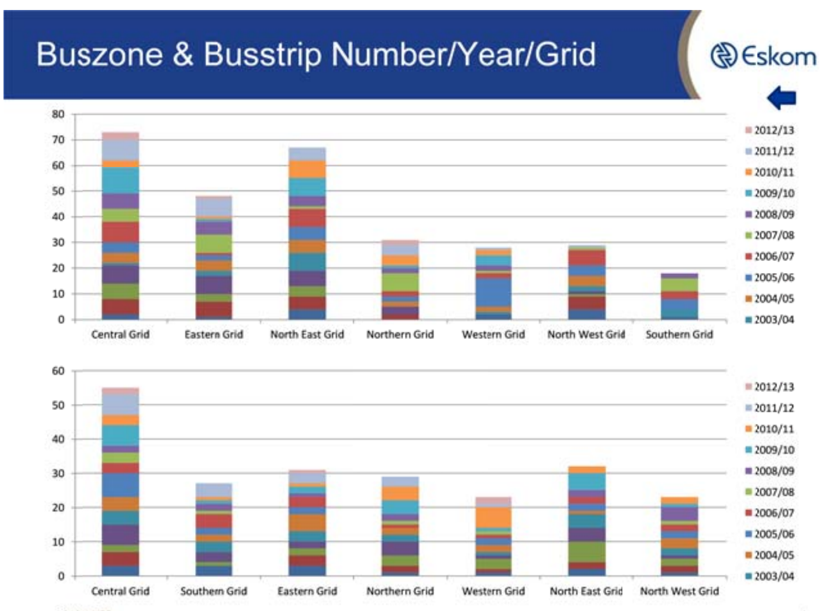


Figure 1: Number of Buszone and Busstrip Incidents over last ten years

The Figure 1 indicates that in the last few years, since 2008 the number of incidents has increased. The overall cause is mainly primary plant but in the last four years or so it has moved to human error.

In analysis performed due to the high number of incidents in 2011 human error was shown as 56% of the reasons for the incident occurring.

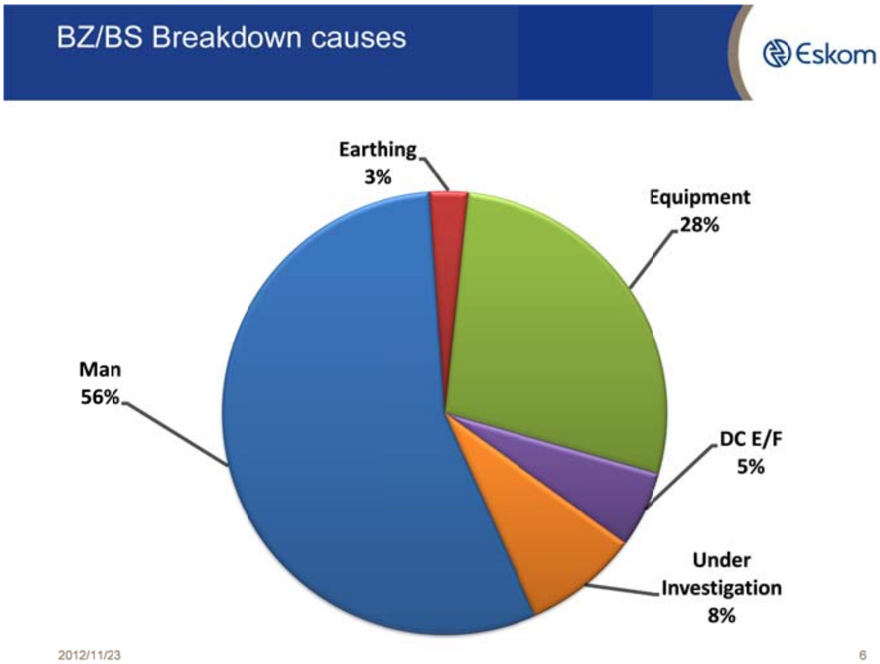


Figure 2: Causes of bz/bs incidents in 2011 jan to june.

Of the incidents recorded over the past 10 years 36% resulted in loss of power. It is thus felt necessary that the impact of human error should be mitigated where possible.

1) Opinion of the western grid relating to breaker and a half

The following was presented as suggested reasons why breaker and a half will meeting the user requirements. Comments in brackets from Substation design CoE:

a) System reliability

- Busbar faults only trip out the faulted busbar. No circuits are interrupted reducing the impact of busbar faults
- Breaker fail of a circuit's breaker (busbar side circuit breaker) will strip the associated busbar and trip the Tie breaker. No other circuits will be interrupted reducing the impact of stuck breaker incidents.
- Diameter can be closed when circuit is out for maintenance, improving system redundancy?
- Eliminates negative impact incorrect bus zone protection trips.
- No security linking required.
- Breakers, CTs and VTs can be maintained on all circuits without interrupting the circuit. Increasing plant availability for maintenance.
- There are no outboard CTs and VTs on the lines, hence lines only have to be taken out to maintain isolators. Increase circuit availability.(No outboard CTs on lines, but will have outboard VTs for line protection)

- No need to disconnect lines to maintain outboard CTs and VTs. This is a major safety benefit. No outboard CTs on lines, but will have outboard VTs for line protection)
- With 2 breakers connecting lines into substations will improve the probability of a successful ARC (ARC is initiated through one breaker only (BB side breaker). If the breaker stays in, the second breaker (Tie breaker) closes).
- When auto reclosing you close the bay breaker first with the busbar separating it from the other circuits

b) Reduction in switching operations (and possibly operator errors).

- No double busbar selection, hence no swinging of busbars. Reduces the number of operations by more than 50%.
- No complicated procedure to put feeders on transfer, eliminating the switching and the writing of complicated transfer procedures for each bay.
- Operators do not have to check the status of the equipment in the yard. All isolators and breakers are normally closed when in service and all BAH substations are the same. (Electrically this is true, however the physical positioning of the equipment may differ, particularly in the conversion of a brown-fields station).
- When switching a breaker out for maintenance you open the breaker, open the isolators, earth and maintain.
- Reduction in the number of operations reduces the probability of making an operating error.
- No complicated transfer procedures.
- No swinging of busbars.
- Simplicity of station layout.
- When all circuits are in service all breakers and isolators are closed. Do not have to verify status of isolators.
- Outages of circuits are a simple operation of open breaker, open isolators and earth.
- Most operating errors occur when swinging busbars, which involves the loss of a busbar

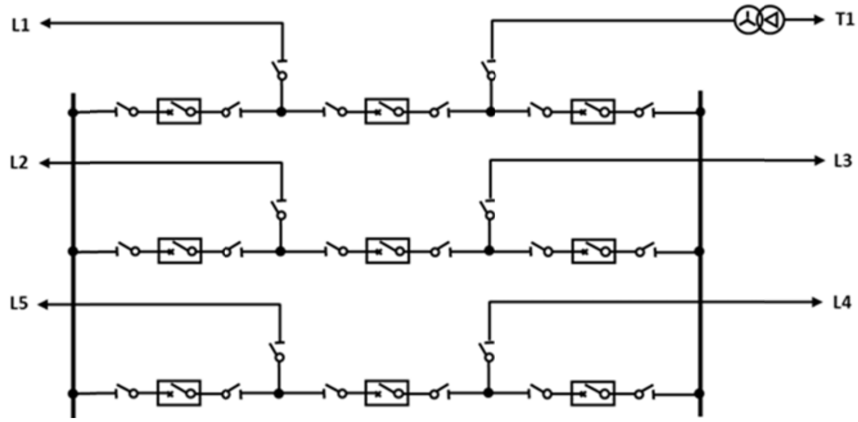
2) Opinion of System operations

Discussions with System operations (Gav Hurford, (Corporate Specialist System Operations), R. Candy (Senior consultant Energy Management), Robbie van Heerden (GM System Operations)) resulted in the following opinions being expressed:

- Breaker and a half will result in more flexibility and less steps required to operate. However, the difference between double bus with bypass and breaker and a half does not warrant any extra cost.
- Double bus with transfer has been in Eskom for 75 years and there is no major reason to alter the layout which has been proved adequate.
- The issue of two different layouts in one substation will not be an issue if there is interlocking (R. Candy). However, according to GM (System Operations), the interlocking is not always in place for the life of the station. An example is Alpha 765/400kV where the interlocking has been removed to allow for certain operations not originally catered for. Thus the different layout per voltage level is a matter of concern and may lead to confusion. (GM (System Operations) stated that he is not sure what benefit breaker and a half will have and will introduce the added issue of confusing operators).
- Layout choice should be a function of cost and perhaps the size of the footprint between the two.

Annex B - Diagrams of different substation layouts

1) Breaker and a half



2) Double busbar with bypass

Figure 8.2 Double busbar with bypass (one can add sectionalisers as well (not shown)