

	Standard	Technology
---	-----------------	-------------------

Title: **GUIDELINE FOR THE
APPLICATION OF INTRA-SPAN
(FLYING) INSULATORS**

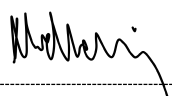
Unique Identifier: **240-114794277**

Alternative Reference Number: **<n/a>**

Area of Applicability: **Engineering**

Next Review Date: **STABILISED**

COE Acceptance



Subhas Maharaj

Senior Manager: Substation Engineering

Date: 20 June 2022

DBOUS Acceptance



Amelia Mtshali

**Senior Manager-Design Base & Outage
COE**

Date: 20 June 2022

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	
3	Established and accepted practices.	x

This letter is for multiple documents: N/A

PCM Reference: **240-53459042**

SCOT Study Committee Number/Name: **Substations**

Title: **GUIDELINE FOR THE
APPLICATION OF INTRA-SPAN
(FLYING) INSULATORS**

Unique Identifier: **240-114794277**

Alternative Reference Number: **N/A**

Area of Applicability: **Engineering**

Documentation Type: **Guideline**

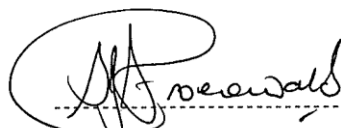
Revision: **1**

Total Pages: **12**

Next Review Date: **November 2021**

Disclosure Classification: **Controlled
Disclosure**

Compiled by

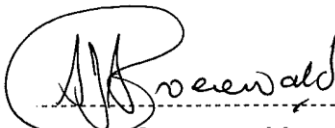


Braam Groenewald

**Corporate Specialist-
Substations**

Date: *25-10-2016*

Approved by



Braam Groenewald

**Corporate Specialist-
Substations**

Date: *25-10-2016*

Authorized by



Phineas Tlhatlhetji

**Senior Manager-Substation
Engineering**

Date: *26/10/2016*

Supported by SCOT/SC



Phineas Tlhatlhetji

SCOT/SC Chairperson

Date: *26/10/2016*

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
2.2.3 General	3
2.2.4 Disclosure classification	3
2.3 Abbreviations	4
2.4 Roles and responsibilities	4
2.5 Process for monitoring	4
2.6 Related/supporting documents	4
3. Document content	4
3.1 Intra-span or Flying Insulator Application in a Feeder Bypass Circuit	4
3.2 Intra-span or Flying Insulator Application in a Transformer Circuit	9
3.3 Intra-span or Flying Insulator Application in an External Line Circuit Breaker Bypass	10
3.3.1 Bypass Switched In	11
3.3.2 Bypass Switched Out	11
3.3.3 Conclusion	11
4. Authorization	11
5. Revisions	12
6. Development team	12
7. Acknowledgements	12

Figures

Figure 1: Lightning Surge Propagating Down Line	5
Figure 2: Standard Lightning Impulse	5
Figure 3: External 400kV Equipment	8
Figure 4: Intra-span Flying Insulators b_1 and a_4	9
Figure 5: Relationship of Primary and Secondary Vectors at a Substation	9
Figure 6: Intra-span (Flying) Insulator across an External Line Bypass Circuit Breaker	10

Tables

Table 1: Intra-span Voltage Ratings	7
---	---

1. Introduction

This document discusses the methods of determining the voltage insulation level that should be applied across a gap bridged by an insulator when the two sides of the gap is connected through a non-switchable device and when the gap is connected through a switchable device.

2. Supporting clauses

2.1 Scope

The document refers to AIS substations where either stranded flexible conductors or round tubular conductors are employed for busbars, equipment interconnections and connections between equipment and busbar conductors.

2.1.1 Purpose

The purpose of this document is to provide logical reasoning for using either stranded flexible conductor or tubular conductors for substation busbars.

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] Substation Layout Design Guide.

2.2.2 Informative

None

2.2.3 General

Definition	Description
Intra-span (Flying) Insulator	An insulator connected in series with a conductor for the purpose of providing a neutral section. Both sides of the insulator are live.
Non-switchable Device	A device connected in series with conductors that does not operate with the opening of contacts and result in breaking of a circuit as part of its normal operation. Human intervention is required to disconnect clamps when the circuit is off.
Switchable Device	A device connected in series with conductors that does operate with the opening of contacts and result in breaking of a circuit as part of its normal operation, e.g. circuit breaker, isolator. Human intervention is not required to disconnect clamps when the circuit is off.

2.2.4 Disclosure classification

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

ESKOM COPYRIGHT PROTECTED

2.3 Abbreviations

Abbreviation	Description
AIS	Air insulated system
BIL	Basic Insulation Level
CT	Current transformer
CVT	Capacitor voltage transformer
GIS	Gas insulated system
PD	Potential difference
PI	Post insulator
SA	Surge arrester

2.4 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.

2.5 Process for monitoring

The document is to be updated from time to time as the technology develops.

2.6 Related/supporting documents

Not applicable.

3. Document content

3.1 Intra-span or Flying Insulator Application in a Feeder Bypass Circuit

Figure 1 illustrates the application of installing an intra-span (flying) insulator for the purposes of forcing current to flow through the current transformer. This insulator is merely placed in series with the conductor to create a discontinuity and high impedance to redirect current flow through the current transformer. Under system healthy and in the steady state, the voltage across the this insulator is for all practical purposes zero.

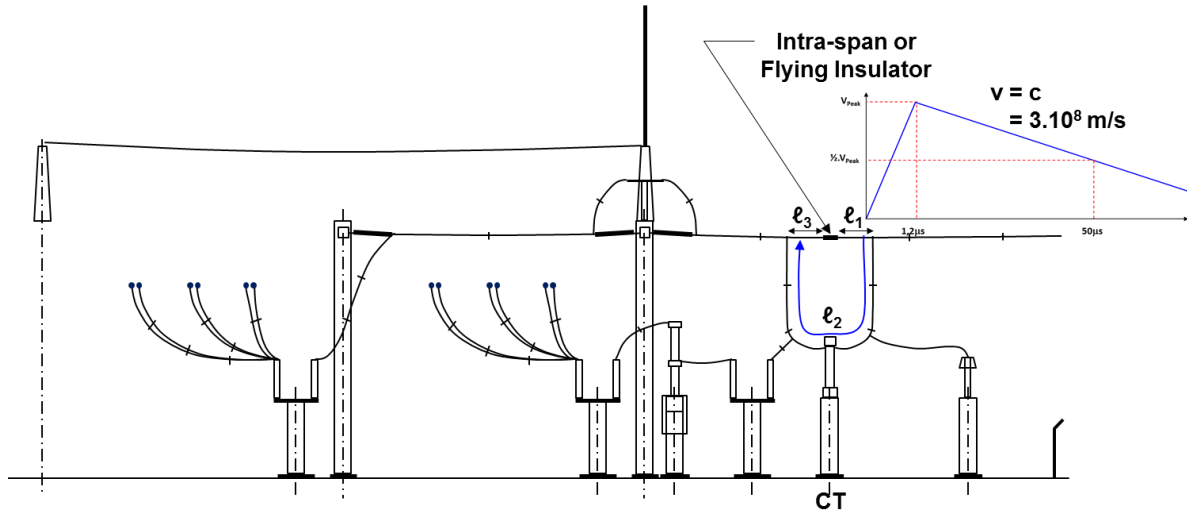


Figure 1: Lightning Surge Propagating Down Line

The above is, however, not true under transient conditions and where steep fronted waves are concerned. Where steep fronted waves are considered, a voltage does develop across the insulator. The voltage rating of the insulator can be determined by considering a lightning surge travelling down the line, towards the substation. For the purposes of simulation, a representative impulse is considered, with a rise time to the peak value of $1,2\mu\text{s}$ and a tail decaying to half the peak value within $50\mu\text{s}$, hence $1,2/50\mu\text{s}$ impulse. It is also assumed that the surge arrester does not operate and clamp the voltage at $1,8\text{pu}$.

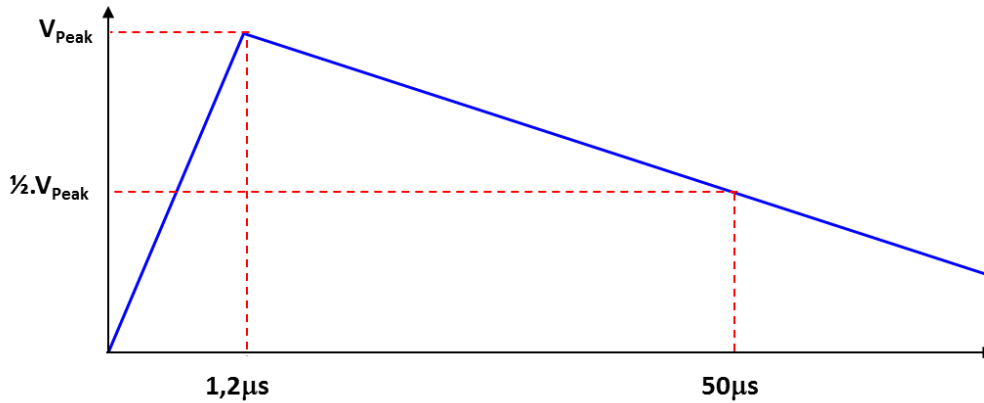


Figure 2: Standard Lightning Impulse

If the peak value of the voltage is V_{peak} , then the voltage gradient of the wave front is given by:

$$\begin{aligned} V_{\text{grad}} &= \frac{V_{\text{peak}}}{t} \\ &= \frac{V_{\text{peak}}}{1,2 \cdot 10^{-6}} \text{ (kV/s)} \end{aligned} \quad \text{Eq.1}$$

All the primary equipment within a substation bay has a **BIL** rating which is related to its voltage and these are all tested to withstand a given peak value, which in this case is in fact the **BIL**. Therefore:

$$V_{\text{grad}} = \frac{\text{BIL}}{1,2 \cdot 10^{-6}} \text{ (kV/s)} \quad \text{Eq.2}$$

The additional or effective distance that the impulse wave needs to travel to the opposite side of the insulator is designated l_{eff} m.

$$\ell_{\text{eff}} = \ell_2 + \ell_3 - \ell_1 \quad \text{Eq.3}$$

The velocity of the wave is **c** (or $3 \cdot 10^8$) m/s so that the time taken for the wave to travel the distance ℓ_{eff} m can be determined by the well-known relationship:

$$v = \frac{\ell_{\text{eff}}}{t} \quad \text{Eq.4}$$

$$t = \frac{\ell_{\text{eff}}}{v} \text{ (s)}$$

The potential difference (**PD**) that develops across the insulator will then be given by product of the voltage gradient (V_{grad}) and the time it takes to move distance ℓ_{eff} m.

$$\text{PD} = \frac{\text{BIL}}{1,2 \cdot 10^{-6}} \cdot t \text{ (kV)} \quad \text{Eq.5}$$

The rated value of the insulator is the next standard voltage above **1,1.PD**.

Sample Calculation 1

Suppose this is applied to a 132kV feeder bay.

BIL = 550kV

The additional or effective distance that the impulse wave needs to travel to the opposite side of the insulator is designated ℓ_{eff} m.

$\ell_{\text{eff}} \approx 2 \cdot (\text{height of stringer} - (\text{height of steel support} + \text{height of equipment})) + \text{horizontal distance of connection}$

$$= 2 \cdot (10,668 - (2,500 + 1,200) + 1,000)$$

$$= 15,936\text{m}$$

Time taken to travel 15,936m:

$$t = \frac{\ell_{\text{eff}}}{v}$$

$$= \frac{15,936}{3 \cdot 10^8} \quad \text{from Eq.4}$$

$$= 53,12\text{ns}$$

Potential difference developed across insulator:

$$\text{PD} = \frac{\text{BIL}}{1,2 \cdot 10^{-6}} \cdot t$$

$$= \frac{550}{1,2 \cdot 10^{-6}} \cdot 53,12 \cdot 10^{-9} \quad \text{from Eq.5}$$

$$= 24,35\text{kV}$$

It is good practice to add 10% to the calculated value in order to take into account slight variations in the steepness of the wave front.

$$\text{PD}' = 24,35 \cdot 1,1$$

$$= 26,78 \text{ kV}$$

The next standard voltage level is 33kV. The insulator should therefore be rated for **33kV** in the case of 132kV bays.

ESKOM COPYRIGHT PROTECTED

NB: This philosophy should not be applied to cases where there is a switch action, e.g. across an isolator or across a circuit breaker where phase-to-earth or phase-to-phase voltage can develop across the insulator. This is only to be used in cases where connections are permanent.

Based on similar reasoning, the rated voltage for Intra-span insulators for other voltage levels can be calculated and are shown in Table 1 below.

Wave velocity = 3.10^8 m/s

Wave front = $1,2.10^{-6}$ s

Table 1: Intra-span Voltage Ratings

Voltage (kV)	BIL (kV)	ℓ (m)	t (10^{-9} s)	PD (kV)	PD' (kV)	Nearest Standard Voltage (kV)
11	95	10.01	33.37	2.64	2.91	11
22	150	9.777	32.59	4.07	4.48	11
33	200	9.55	31.83	5.31	5.84	11
66	350	11.310	37.70	11.00	12.10	22
88	380	13.888	46.29	14.66	16.13	22
132	550	15.936	53.12	24.35	26.78	33
220	825	21.342	71.14	48.91	53.80	66
275	1050	20.342	67.81	59.33	65.26	88
400	1425	31.444	104.81	124.47	130.69	132

Important Note: Table 1 is purely for guidance and where the $\ell_1 \approx \ell_3$ as shown in Figure 3 below. If this is not the case, then Sample Calculation 2 should be followed.

Sample Calculation 2

Figure 3 applied to a 400kV feeder bay.

$\ell_1 = 1,5\text{m}$, $\ell_2 = 46,2\text{m}$, $\ell_3 = 15,1\text{m}$

BIL = 1425kV

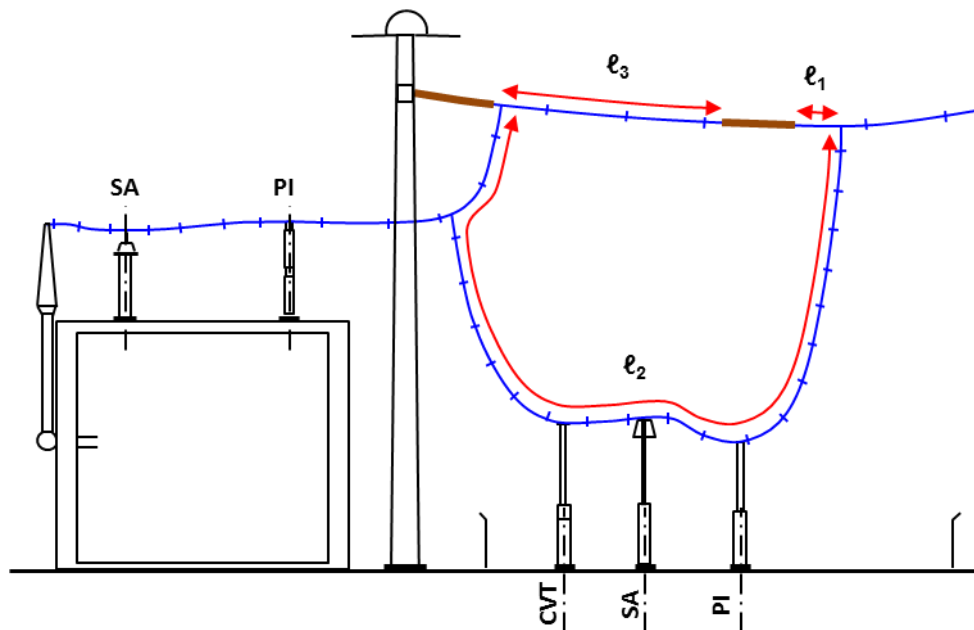


Figure 3: External 400kV Equipment

The additional or effective distance that the impulse wave needs to travel to the opposite side of the insulator is designated ℓ_{eff} m.

$$\begin{aligned}\ell_{\text{eff}} &= \ell_2 + \ell_3 - \ell_1 \\ &= 46,2 + 15,1 - 1,5 \\ &= 59,8\text{m}\end{aligned}$$

from Eq.3

Time taken to travel 59,8m:

$$\begin{aligned}t &= \frac{\ell_{\text{eff}}}{v} \\ &= \frac{59,8}{3 \cdot 10^8} \\ &= 199,33\text{ns}\end{aligned}$$

from Eq.4

Potential difference developed across insulator:

$$\begin{aligned}PD &= \frac{BIL}{1,2 \cdot 10^{-6}} \cdot t \\ &= \frac{1425}{1,2 \cdot 10^{-6}} \cdot 199,33 \cdot 10^{-9} \\ &= 236,70\text{kV}\end{aligned}$$

from Eq.5

It is good practice to add 10% to the calculated value in order to take into account slight variations in the steepness of the wave front.

$$\begin{aligned}PD' &= 236,705 \cdot 1,1 \\ &= 260,37\text{ kV}\end{aligned}$$

The next standard voltage level is 275kV. The insulator should therefore be rated for **275kV** in the case of this **400kV** bay. It may be just as well to put in 400kV insulators.

ESKOM COPYRIGHT PROTECTED

3.2 Intra-span or Flying Insulator Application in a Transformer Circuit

Figure 4 illustrates the application of intra-span flying insulators b_1 and a_4 .

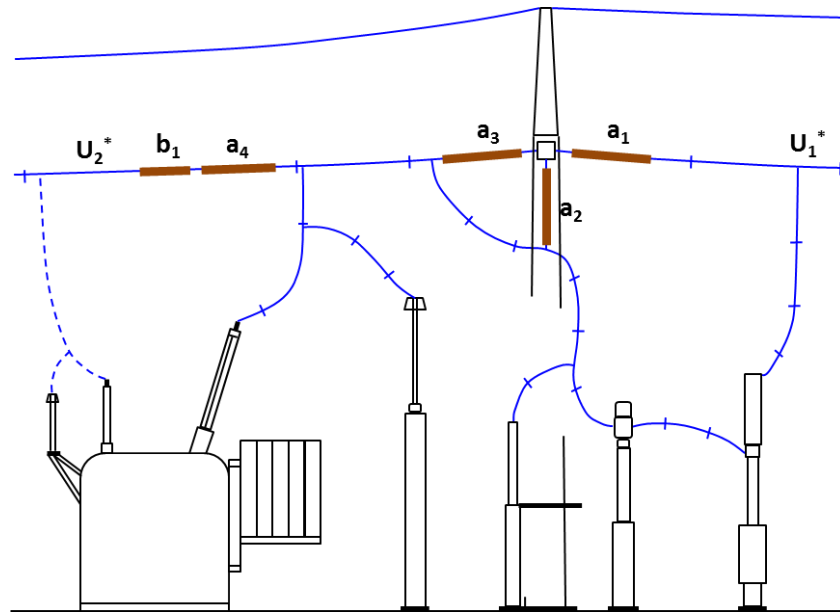


Figure 4: Intra-span Flying Insulators b_1 and a_4

It is necessary to be able to determine the worst case voltage that can develop across the insulator b_1 - a_4 to ensure that a flash-over does not occur. In order to analyse the behaviour of the voltage across b_1 - a_4 , vector diagrams as illustrated in Figure 5 are discussed. Note that there is a high impedance element i.e. the power transformer between the primary and secondary systems.

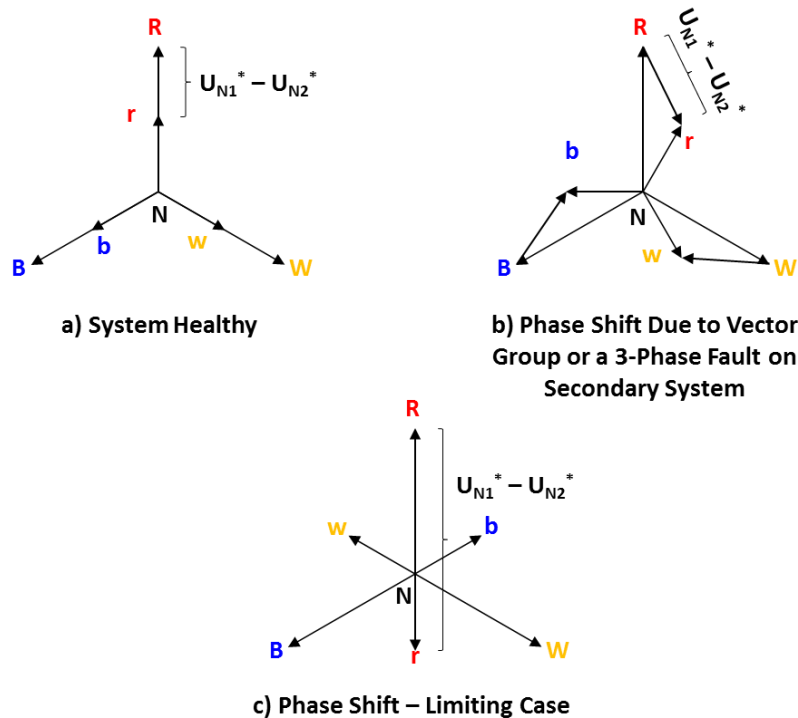


Figure 5: Relationship of Primary and Secondary Vectors at a Substation

ESKOM COPYRIGHT PROTECTED

Figure 5a shows the phase relationship between the primary and secondary voltages when considering a system healthy condition. The voltages of corresponding phase are aligned, i.e. there is no phase shift, and the voltage across b_1-a_4 is the vector difference $U_{N1}^* - U_{N2}^*$ with zero angle between them.

If there is a fault on the secondary system, and depending on the configuration of the system on the secondary side, the phases can start to shift, causing an angle to develop between the primary and secondary. The voltage across the insulator b_1-a_4 will start to increase. This is illustrated in Figure 5b. How much this angle will increase is a function of system parameters and configuration.

Without knowledge of how the complete system is configured at any one time and without detailed network studies to provide decision making information, it is best to design for an absolute worst case that could in theory develop. This worst case occurs when the primary and secondary are 180° out of phase (Figure 5c), a somewhat unrealistic scenario, but without evidence, becomes the limiting case. The vector difference between the primary and secondary voltages now effectively becomes the vector sum due to the change in sign. The voltage that is developed in this scenario is therefore:

$$PD = U_{N1} + U_{N2} \text{ (kV)} \quad \text{Eq.6}$$

The above is a phase to earth value but it can easily be interpreted as a phase-to-phase equivalent.

Sample Calculation 3

Supposing the primary voltage is 275kV while the secondary voltage is 132kV, the equivalent insulator set is that a_3 should be a **275kV** insulator and b_1 , a **132kV** insulator.

3.3 Intra-span or Flying Insulator Application in an External Line Circuit Breaker Bypass

The scenario here is the provision of an external AIS bypass circuit breaker in order to re-energise a line and re-establish supply in the event of a GIS busbar failing. In this case, the same voltage is involved on both sides of the external circuit breaker. The result is that both cases as described in paragraphs 3.1 and 3.2 can occur depending on whether or not the bypass is in service. With the bypass switched in, paragraph 3.1 applies, while with the bypass switched out, paragraph 3.2 applies.

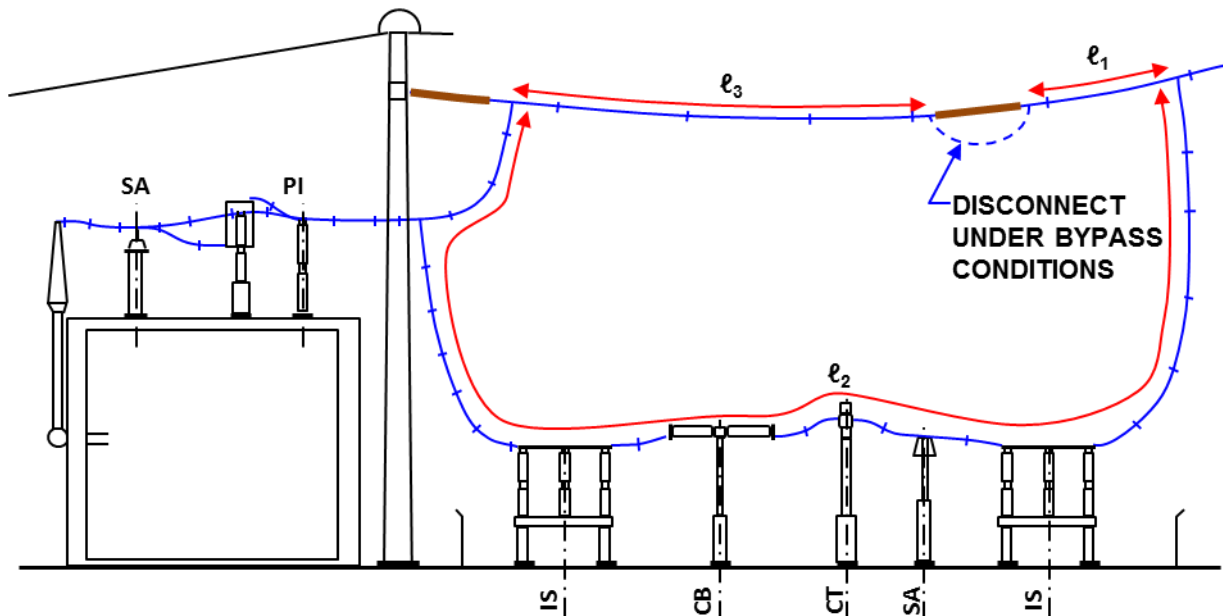


Figure 6: Intra-span (Flying) Insulator across an External Line Bypass Circuit Breaker

3.3.1 Bypass Switched In

Figure 6 applied to a 400kV feeder bay.

$$\ell_1 = 8,5\text{m}, \ell_2 = 56,0\text{m}, \ell_3 = 28,0\text{m}$$

$$\text{BIL} = 1420\text{kV}$$

The additional or effective distance that the impulse wave needs to travel to the opposite side of the insulator is designated ℓ_{eff} m.

$$\begin{aligned}
 \ell_{\text{eff}} &= \ell_2 + \ell_3 - \ell_1 \\
 &= 56,0 + 28,0 - 8,5 \\
 &= 75,5\text{m}
 \end{aligned}
 \tag{from Eq.3}$$

Time taken to travel 75,5m:

$$\begin{aligned}
 t &= \frac{\ell_{\text{eff}}}{v} \\
 &= \frac{75,5}{3 \cdot 10^8} \\
 &= 251,67\text{ns}
 \end{aligned}
 \tag{from Eq.4}$$

Potential difference developed across insulator:

$$\begin{aligned}
 \text{PD} &= \frac{\text{BIL}}{1,2 \cdot 10^{-6}} \cdot t \\
 &= \frac{1425}{1,2 \cdot 10^{-6}} \cdot 251,67 \cdot 10^{-9} \\
 &= 298,85\text{kV}
 \end{aligned}
 \tag{from Eq.5}$$

It is good practice to add 10% to the calculated value in order to take into account slight variations in the steepness of the wave front.

$$\begin{aligned}
 \text{PD}' &= 298,85 \cdot 1,1 \\
 &= 328,74 \text{ kV}
 \end{aligned}$$

The next standard voltage level is 330kV. The insulator should therefore be rated for **330kV** in the case of this 400kV bay. It may be just as well to put in **400kV** insulators.

3.3.2 Bypass Switched Out

If the circuit breaker is open, the two systems either side of the insulator are disconnected. Referring to paragraph 3.2, this means that the voltage phasors could theoretically be 180° apart. This will in effect mean that double phase to earth voltage can occur across the insulator, hence 2x400kV insulators are required.

3.3.3 Conclusion

Since the larger of the two scenarios is given by that in paragraph 3.2, then 2x400kV insulators are to be installed.

4. Authorization

This document has been seen and accepted by:

ESKOM COPYRIGHT PROTECTED

Name and surname	Designation
Phineas Tlhatlhetji	Senior Manager - Substations
Braam Groenewald	Corporate Specialist - Substations
Enderani Naicker	Chief Engineer - Substations
Mark Pepper	Chief Engineer - Substations
Sipho Zulu	Chief Engineer - Substations
Derrick Delly	Chief Engineer - Substations
Rukesh Ramnarain	Chief Engineer - Substations
Theunus Marais	Chief Engineer - Substations
Ian Hill	Senior Technologist - Substations

5. Revisions

Date	Rev	Compiler	Remarks
Nov 2016	1	AJS Groenewald	First Issue.

6. Development team

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

- Braam Groenewald Technology Group Johannesburg

7. Acknowledgements

Not applicable.