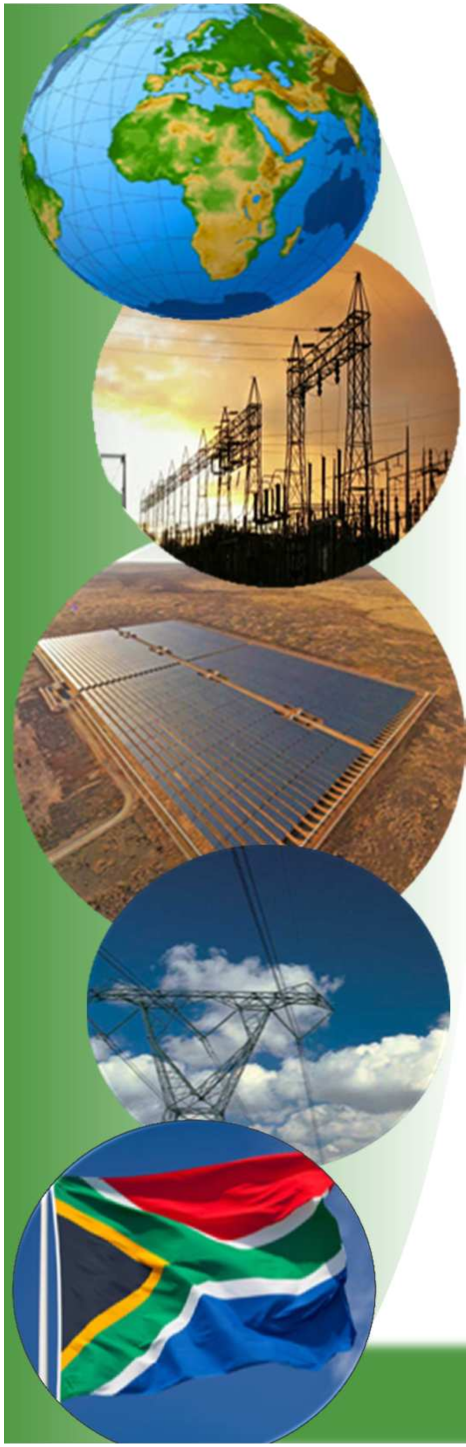

Pre-emptive tripping of distribution power transformers for decaying auxiliary DC supply

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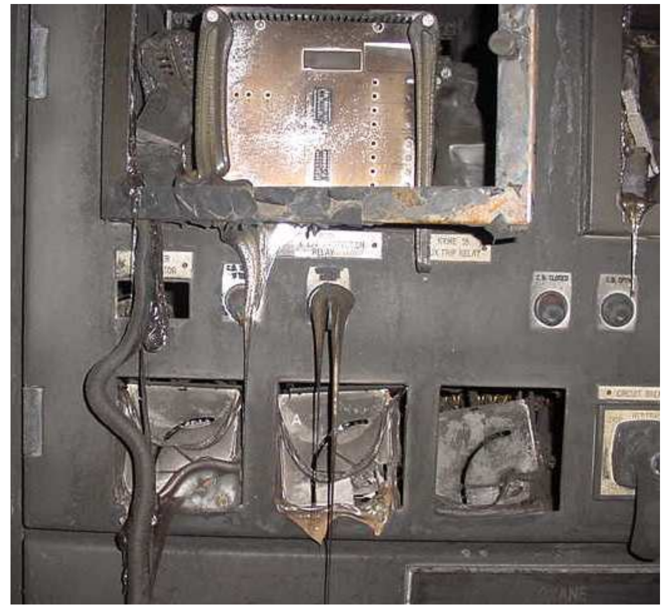
Substation failures attributed to DC failure

- Mpumalanga: 132/22kV 20MVA substation – Sept 2003



- Catastrophic failure of 2 x 10MVA transformers, NECRs and MV switchgear/relay room.
- Substation DC failure – no protection.

Substation failures attributed to DC failure

- Gauteng 40MVA substation – Aug 2010

- Catastrophic failure: Transformer, NECR and MV switchroom / relay room.
- Substation DC failure – no protection.

Substation failures (DC failure?)

- May 2017, looks familiar?

Mooikloof substation goes up in flames

PRETORIA NEWS / 23 MAY 2017, 4:18PM /

The Mooikloof substation goes up in flames.

Staff Reporter

Some suburbs in Pretoria East have been left without power following a fire outbreak at the Mooikloof 132KV substation.The City of Tshwane's Emergency Services is currently on site distinguishing the fire. It is only after the fire has been put out that the cause and cost will be determined.

The following areas were left without power: Moreleta Park, Pretorius Park, Garsfontein, Boardwalk Meander, Woodhill, The Wilds, Mooikloof, Mooikloof Ridge, Onbekend, Zwavelpoort and Mooikloof Agricultural Holding.

It is estimated that some areas could be without power for 5-7 days

https://www.iol.co.za/pretoria-news/mooikloof-substation-goes-up-in-flames-9302861

Substation failures attributed to DC failure

- Over the past 20 years, Eskom Distribution has experienced at least 10 similar failures, one involving an employee fatality.
- A rare event in a power system comprising >2000 substations (<0.025% chance per substation per year).
- This paper examines:
  - "Why does this happen? Don't you have back-up protection?"
    - Causes and consequences of substation DC failure.
    - Some faults cannot be detected from remote upstream substations.
  - Protection options
    - Pre-emptive tripping due to low station DC as applied in Gauteng since Nov 2010.
  - Opportunities and Risks
    - Dependability and Security of chosen solution.
    - What price would you be willing pay to avoid this?

Basics of Substation DC, DC failure

- Power System Protection is:

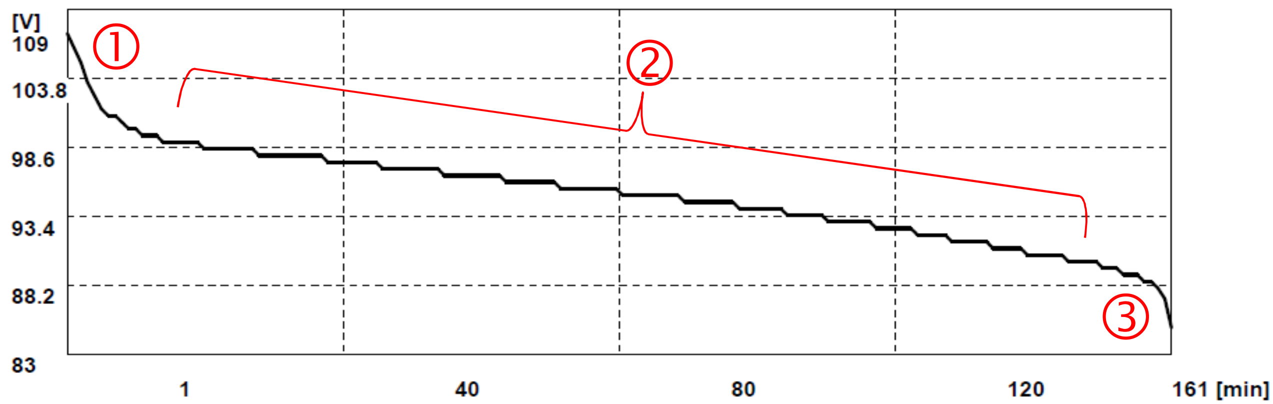
  "Provisions for the detection of faults and other abnormal conditions in a power system, for enabling fault clearance, for terminating abnormal conditions, and for initiating signals or indications." [IEV 448-11-01]

- Substation protection is typically powered by a DC battery system which also provides energy for tripping of circuit-breakers
  - Provides between 12-hour and 10 days stand-by in the event of loss of AC supply to the substation.

- DC system health is remotely monitored via SCADA
  - Provision of SCADA communication at a substation allows DC systems to be designed with shorter stand-by times (hours).

Basics of Substation DC, DC failure

- Typical substation battery discharge curve (15A fast discharge):



1. Loss of AC supply to charger: battery voltage drops from “float” level.
2. Gradual decay in voltage as batteries discharge:
   – Rate depends on battery capacity and standing load
3. Rapid decay in voltage: depletion of battery energy.

- Secondary equipment lower operating thresholds:
  – Protective relays (IEC 60255): 80% of Nominal (88V on 110V system).
  – Circuit-breaker tripping coils (IEC 62271): 70% of Nominal (77V).

Basics of Substation DC, DC failure

- Causes of DC system failure:
  1. AC supply failure to battery charger
  2. Battery charger failure
  3. Fault on DC system
     - Tiered system design means complete failure by this mode is rare

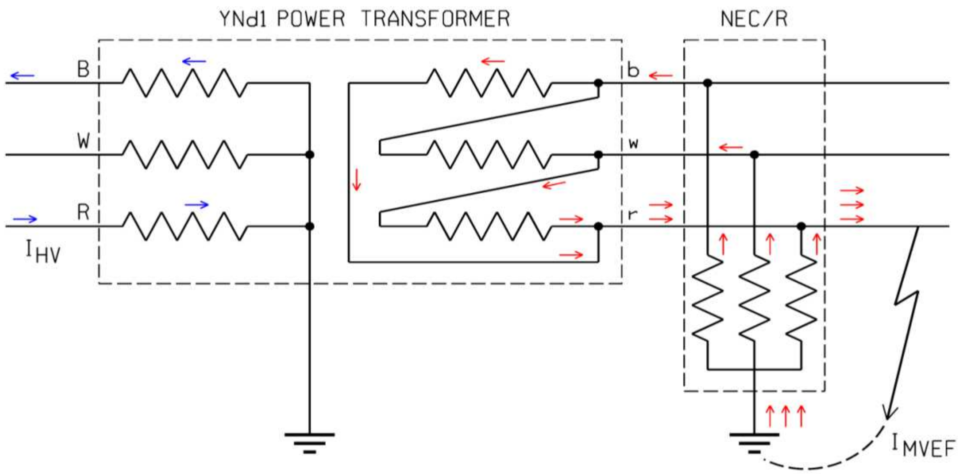
  (1, 2) "Decaying DC" scenario
  (3) Sudden and complete loss of DC

- Catastrophic substation failure is always a result of at least two systemic failures, coupled with a power system fault condition:
  1. DC system fault
  2. Failure of DC system fault notification/response
     - SCADA communication system failure
     - Failure of human response
  3. Power system fault which is not detected/cleared

Remote back-up protection

Most catastrophic failures occur a HV/MV substations

- MV networks are Resistively Earthed: 360A fault level

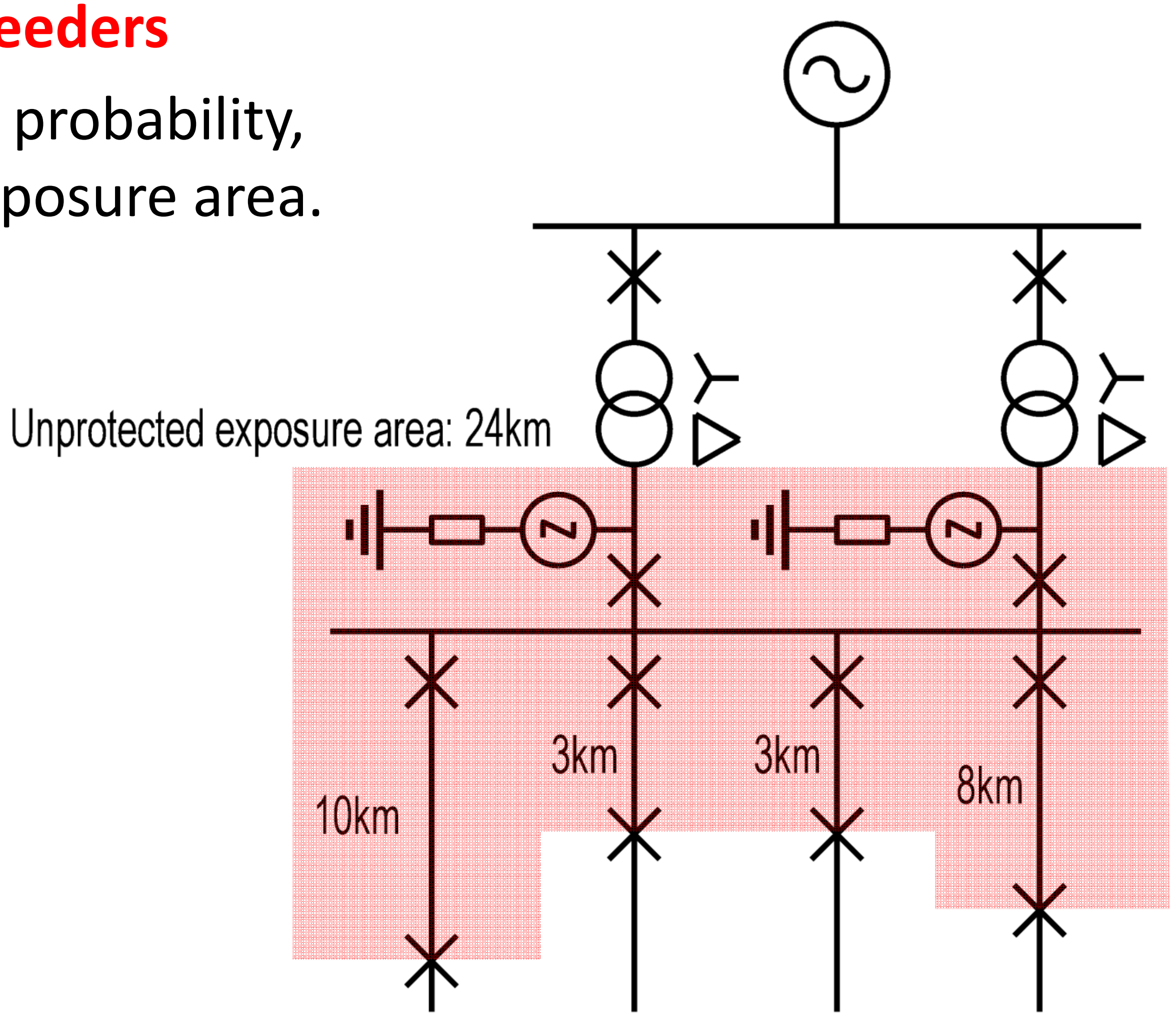


- Fault current seen from HV side of Yd Transformer: $I_{HV} = \frac{I_{MVEF} \times N_2}{3 \times N_1}$
  - 360A @ 22kV = 34A @ 132kV (7.7 MVA)
  - 360A @ 11kV = 17A @ 132kV (3.9 MVA)
- Not detectable by HV-side earth fault protection. HV-side overcurrent protection pick-up is set above full load
  - An MV-side phase fault is also often undetectable from remote (upstream)

Remote back-up protection

Most catastrophic failures occur a HV/MV substations which supply MV overhead feeders

- Highest fault probability, expansive exposure area.



Remote back-up protection

- The risk at HV/HV (e.g. 132/88kV or 132/44kV) substations is less than for HV/MV but similar considerations may apply.
- "Through faults" on the same network voltage level (e.g. on an interconnected 132kV network) are almost always detected by remote feeder protection – low risk of catastrophic failure.
  - Air-insulated MV indoor switchgear may be at risk as remote "back-up" protection may not operate quick enough to prevent enclosure rupturing in the event of a switchgear fault
- Switching stations may be at increased risk of AC auxiliary supply failure if supply is taken from an MV network. Risk is reduced by applying power VTs at the station.
- **Summary:** the risk of undetected faults due to local DC failure is "caused" by transformers/transformer action. Transformers and MV indoor switchboards are the plant types most at risk.

Risk Assessment per Dx substation type

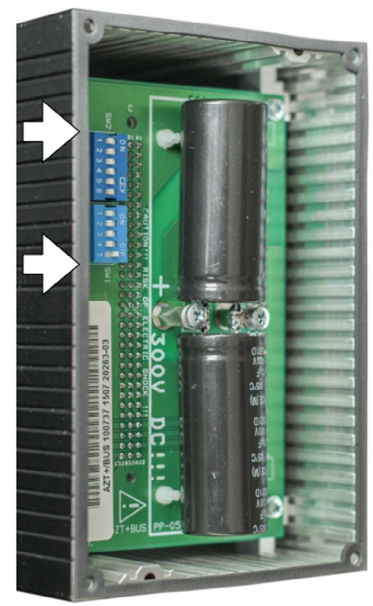
Substation Type	Probability of Loss of DC	Probability of Primary Fault	Consequence	Overall Risk
HV/MV substation – utility MV network	Medium	High (MV Overhead)	Catastrophic failure	**High**
HV/MV Industrial substation – Customer MV network	Low Medium*	Low Medium (MV Cable)	Catastrophic failure	**Medium**
HV/HV substation	Medium	Medium / Low	Catastrophic / Network failure	**Medium / Low**
HV switching station	Medium/ High	Medium / Low	Network outage	**Low**
MV switching station (AIS indoor)	Medium/ High	Low Medium (MV Cable)	Catastrophic failure	**Medium**
		High (MV Overhead)		**High**

* Customer uses independent DC to Utility for network protection

Mitigation measures

- Redundant station DC supplies (with independent AC sources)
  - Standard design philosophy for Transmission substations.
  - Well suited to dual main protection design philosophy.
  - Costs prohibitive for Distribution substations.
- Emergency protection with stored energy
  - Use “self-powered” protection relay together with capacitive energy storage for operating a circuit-breaker tripping coil.
  - Effective for any DC system failure. Installed close to/on primary circuit-breaker can also mitigate risk caused by control cable theft.
  - Selective, Fast protection should primary fault occur.
  - Negative: Cost, capacitor maintenance.
- Implement fail safe design of conventional protection system
  - Pre-emptively trip primary circuit-breakers upon critical loss of DC.

AZT+ by Protecta



Pre-emptive tripping philosophy

- What to trip:
  - **One MV feeder @ substation:** Minimum network disruption, but MV network fault exposure persists. Utility Operator is called to work in a live substation that may be unprotected.
  - **Trip all Transformer MV breakers [PREFERRED for high risk SS's]:** Removes primary fault exposure. Substation auxiliary transformers remain energised, easing DC supply restoration and normalisation of primary supply.
- Protection philosophy – caters for decaying DC scenarios only
  - Trip when station DC reaches 80% of nominal (+ 2V margin) for 60 sec.
  - Do not trip for complete loss of DC (<40%) – nuisance operation, no energy to trip anyway.
  - Measurement accuracy of ± 2Vdc, immune to AC interference and EMI.
  - Distributed system: independent DC voltage level measurement by each transformer protection scheme.

Pre-emptive tripping philosophy

- Protection philosophy (continued):
  - Tripping undertaken by IEC 60255-class numerical protective IED.
  - Circuit-breaker closing blocked whilst trip signal remains active.

- Implications:
  - **Cost of solution/implementation:** Where DC measurement capability is offered by standard transformer protection IED: FREE. Otherwise up to R13k per power transformer(?)
  - **Risk of nuisance operation:** Very low. Drift of DC voltage measurement the only significant risk (limited by specification of measurement device).
  - **Legal:** Legitimate engineering design based on failsafe design principle.
  - **Network performance:** Network SAIDI impact, but significantly less impact (including cost and Public Relations) than a catastrophic SS failure.
  - **Restoration after black-out:** No impediment. Transformer MV circuit-breakers will have tripped, but can be closed remotely once HV supply to substation is restored (restoring substation auxiliary supply).

Eskom Distribution practice

- Applied in Gauteng Operating Unit since 2010:
  - Back fitting to legacy transformer protection schemes (setting implementation).
  - Retrofitting of DC measurement hardware not envisaged.
- Standard design feature (settable option) in transformer protection schemes on National contract since 2010.
- Applied at Eskom Dx HV/MV and HV/HV substations
  - with customer consultation at Industrial substations (trip least significant load) OR cross report DC fail alarms without tripping.
- Performance to date: **3** correct operations (genuine DC decay), **Zero** misoperations.

Conclusion

- Catastrophic substation failures mostly occur during DC supply system failure.
- Very rare occurrences, yet with very severe consequences.
- HV/MV substations are at increased risk of undetected faults due to transformation action and MV neutral earthing philosophy:
  - Transformers and MV indoor switchgear are the plant most at risk.
  - Risk further magnified by MV overhead feeders from substation.
- Pre-emptive tripping of transformer MV circuit-breakers is a cost effective (often zero equip./installation cost) mitigation measure:
  - Seen by some as a controversial, though based on the standard engineering principle of a failsafe design.
  - Does not cater for sudden and complete loss of DC (main DC MCB trip).

Acknowledgement

- **Jock Rizzotto** of Eskom Distribution Northern region first proposed a pre-emptive low DC tripping philosophy in 2008, supported by **Christo van Zyl**.
- Eskom Gauteng Operating Unit's regional implementation of low DC tripping was led by **Paul Gerber** and **Peter Almeida**.
- A National standard philosophy for Eskom Distribution is being drafted by an Eskom SCOT working group convened by **Osie Oosthuizen** (Mpumalanga OU).