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Reliability by design – separable connections on OH lines and what designers should be aware of

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Background

Electrical connections on OH lines:

- Critical for the reliable and long-lasting current-carrying performance
- Susceptible to electromechanical forces and the environment
- **Separable electrical connections** - the most difficult to achieve and maintain
- **Separable electrical contacts** - the key component of any ABS

Field observations of conventional ABS in NZ and Au – visual and acoustic:

- Bad contacts - pitting, erosion, burns, heavy arcing, etc in less than a year in service
- ABS maintenance - focused on contacts (cleaning, greasing, re-alignment...)
- A common thread – exposure to vibrations

Making things worse:

- ABS maintenance reduced due to live-line work restrictions
- Consequences - more ABS failures (e.g. Operational Constraints, unreliable, hazardous, etc.)

We need a more reliable, long-lasting ABS with less maintenance

Deficiencies of the conventional ABS design

Key requirement - a low-resistance contact between the contact blade and fixed contact fork because this contact carries a full load current

The flaw in the design - the spatial relation between contacts and pivoting insulator:

- **The pivoting insulator and the contact surfaces of the blade move in the same (vertical) plane e.g. they are parallel to each other**

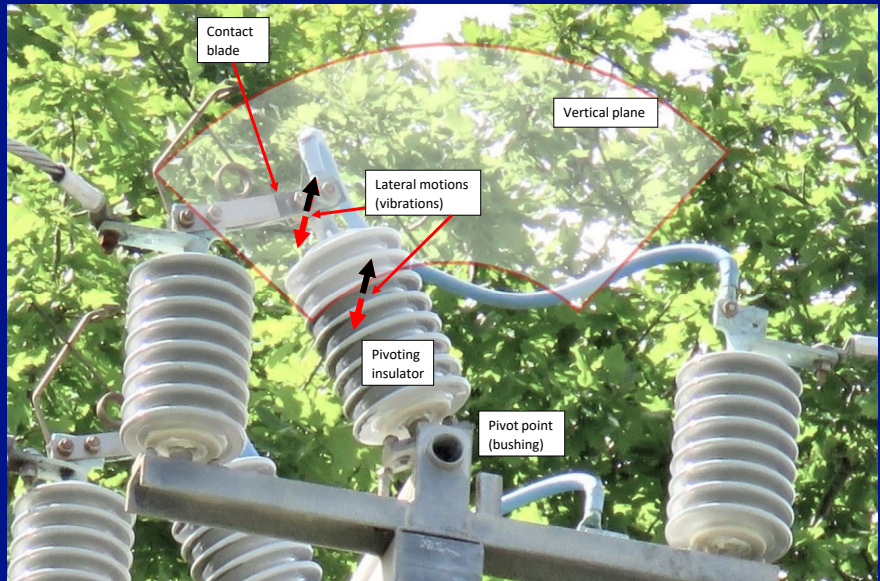
Consequences:

- A sideways movement of the insulator causes equivalent vibrations of the blade/fork in the same direction, causing:
 - Fretting wear on one side
 - Micro-arcing, pitting, and erosion on the other side
 - Gets even worse with moisture, sea spray, pollution, thermal changes, galvanic processes...
 - Self-perpetuating

The flawed **Mechanical design** has significant negative effect on the **Electrical performance** of OH power lines.



Conventional ABS



Note:

Some alternative designs with 2 insulators per phase only - suffer from similar issues with contacts. They are sensitive to vibrations and contacts require perfect aligning. Many distribution companies allow only ABSs with 3 insulators per phase.

The direct analogy with bus-stab contacts in substations

Three types of motions (vibrations) on busbar stabs (aka bus fingers):

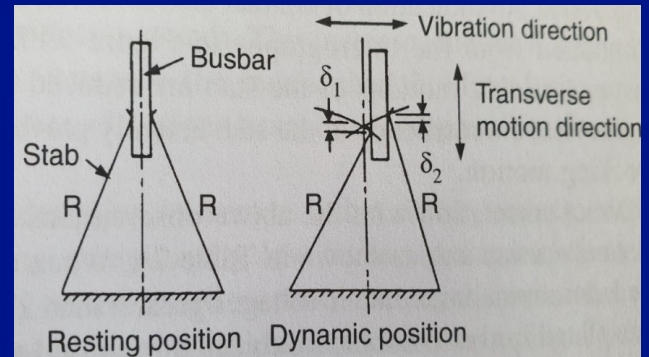
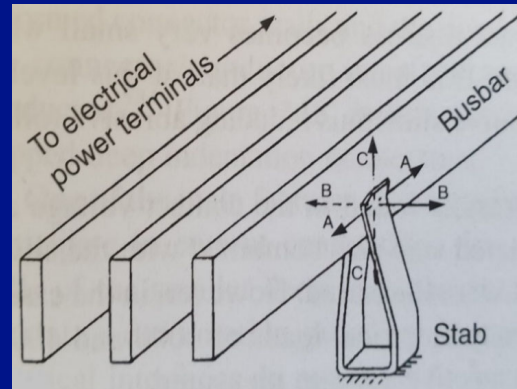
- A-A direction: Slide motion due to variations in electrical load (e.g. thermal expansion and contraction)
- B-B direction: Electromagnetically induced vibrations due to heavy currents in adjacent busbars
Note: The ABS contacts are exposed to similar vibrations

- C-C direction: Transverse displacements (fretting vibrations) perpendicular to both thermal and electromagnetically induced vibrations

- The frequency is 100 Hz

Note:

A bus-stab contact does not carry the load current. However, the micro arcing at such contacts has been confirmed with the acoustic inspection instrument.

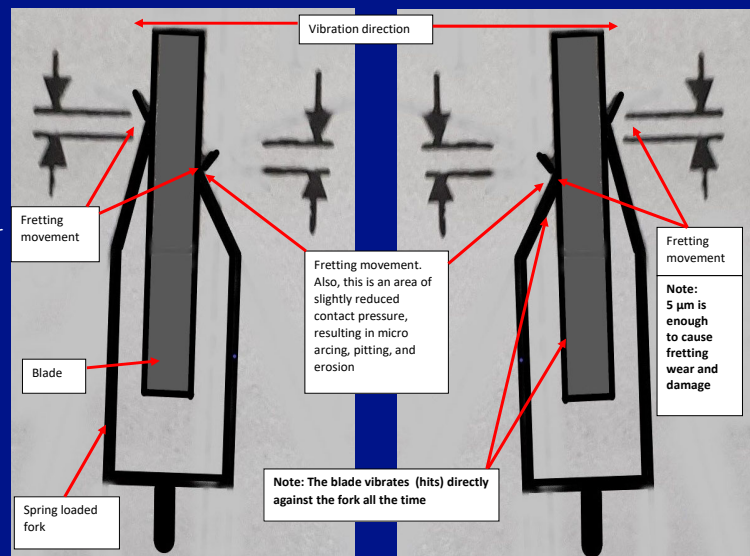


Main electrical contacts of conventional ABS

The same failure mechanism as with bus-stabs, just caused by different vibrations.

The consequences are much worse because the ABS contacts carry a full load current:

- When the blade moves to the right, the fork on that side moves upward, resulting in fretting wear
- At the same time, the opposite finger contact moves downwards, resulting in:
 - Weaker spring effect
 - Reduced contact pressure
 - Increased contact resistance
 - Micro arcing, burning, pitting, and erosion
- A self-perpetuating process



Real-life examples: A 33kV ABS on a line exposed to Aeolian vibrations

Heavy arcing, fretting wear, pitting, and erosion in less than a year in service

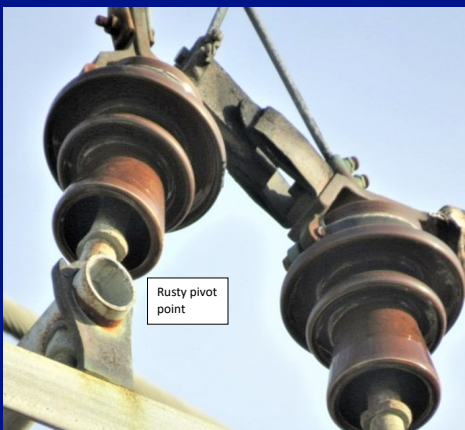
- The line is perpendicular to the steady wind
- Vibrations felt on the pole with a bare hand



Real-life examples: 11kV ABS in a closed position

Heavy arcing, fretting wear, molten metal, pitting, and erosion of the main contacts

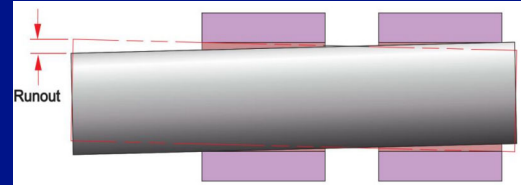
- The ABS along the main road
- Rusty pivot point (bushing)



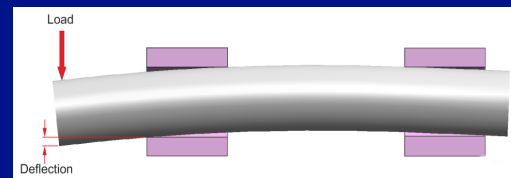
Why are there relative movements between the fixed part of the ABS assembly and the pivoting insulator with the contact blade?

- The pivoting insulator pivots on a shaft around an axis with a bushing (a sleeve bearing).
 - Typical radial clearance of bushings is 0.05-0.10 mm (50 - 100 μm)
 - For comparison – the thickness of human hair is 5 μm
 - Even a small clearance can result in shaft deflection, runout, vibration, and axial motion

- If the bushing radial clearance is only 5 μm , and the middle ABS insulator vibrates:
 - The lateral displacement of the blade is approx. 1.5mm (at 330 mm distance from the pivot point)
 - It produces the transverse (fretting) motion of contacts of approx. 7.5 μm
 - A perfect condition for fretting wear



An illustration of shaft dynamic runout



An illustration of shaft deflection due to side load

What can cause vibrations that affect contacts of conventional ABS

- ABS operation:
 - During closing/opening - any vibration of the pivoting insulator
 - In the stationary closed state - any vibration will form a small gap between the contact surfaces and micro-arcing. Note: the contacts carry a full load current.
- Operation of other hardware on the same or adjacent poles
- Mechanical vibrations due to high winds
- Aeolian vibrations - transferred from the OH conductors to the pole hardware
- Mechanical vibrations from the traffic
- Vibrations induced via the road surface bumps, loose soil, or reclaimed land

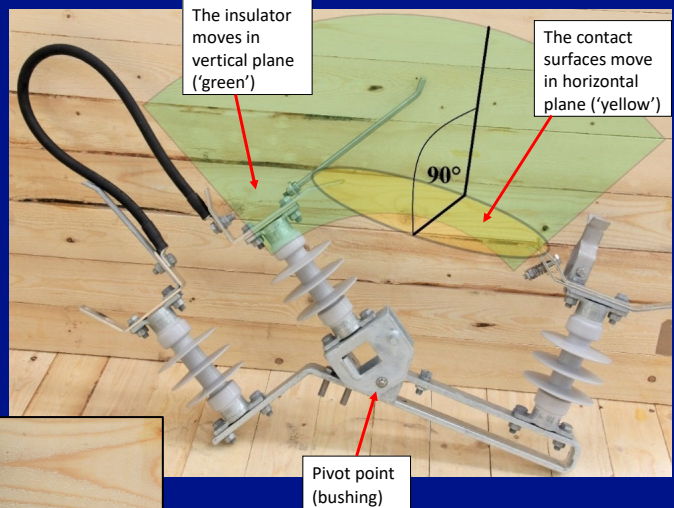
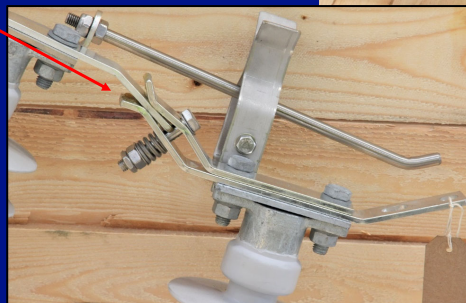
New design of ABS (Note: New to New Zealand)



The key difference

- The middle insulator and contacts are at 90° to each other (e.g. in different planes)
- Lateral vibration of the middle insulator won't affect the contact surfaces between the blade and fork
- If the insulator vibrates, the blade slides between the fork fingers – it does not hit the fork

Note:
The lateral sliding distance is in μm and doesn't affect the contacts



A proof of vibrations on OH lines - direct and indirect

Direct confirmation:

- Vibrations - subtle, in μm
- However, human skin can sense vibrations up to 1,000 Hz, with peak sensitivity around 250 Hz
- By simply putting a hand on a power pole or supporting structure in an area exposed to Aeolian vibrations, one can feel vibrations
- A good example is the 33kV power lines in the Western Australian mining areas
- In New Zealand, by putting a hand on a concrete pole next to the road with the passing traffic, most people will be able to feel vibrations

Indirect confirmation:

- Many loosened nuts & bolts on OH power lines hardware
- If there were no vibrations, they would simply not get loose
- The initial loosening may start with thermal expansion, but will continue and self-perpetuate with mechanical vibrations

Energy (thermal) losses from ABS' during normal operation

All separable connections have a higher contact resistance than permanent connections. Therefore, they have higher energy losses.

Conventional ABS with bad contacts:

- A major increase in contact resistance over time
- Significant heating (energy) losses
- If in-operable, it just sits there and continuously dissipates heat
- Due to energy losses alone - the true cost over the service life can exceed the original price
- Additional costs – regular maintenance, SAIDI, feeder faults, replacements...
- The risk of bush fires from arcing contacts and molten copper

The new ABS design:

- Stable contact resistance
- No increase in heating (energy) losses
- High reliability over the entire service life
- Virtually maintenance-free
- The true cost over the service life does not increase

The results speak for themselves

The new ABS design:

- In use for more than 40 years
- It successfully survived the test of time
- Maintenance - non-existent or minimal (not even greasing is required)

Feedback from distribution companies that adopted this design:

- Improved network reliability, resilience, SAIDI/SAIFI
- Reduced risk of feeder faults due to failed ABS contacts
- Improved public and personnel safety
- Reduced risk of bush fires
- Modular and compact design
- Easy to install – one person can carry individual components

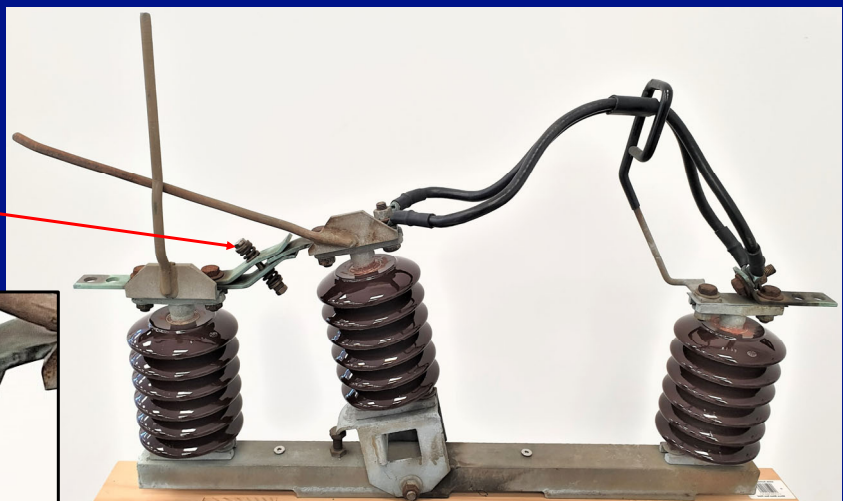
Conclusions and recommendations

- There are thousands of ABSs based on a conventional design in New Zealand
- Most of them are along the roads, exposed to vibrations from traffic, winds, Aeolian, vegetation, etc.
- There is a steady increase in ABS failures with a significant impact on SAIDI/SAIFI

Mechanical and electrical designs of OH lines are inseparable:

- Flawed mechanical design can have heavy consequences on electrical performance of OH lines
- Sometimes an old but proven design can be a much better solution

A picture is worth a thousand words – a recently replaced ABS with near-perfect contacts after 40 years in service





"Good design is actually a lot harder to notice than poor design, in part because good designs fit our needs so well that the design is invisible"

Don Norman - *"The Design of Everyday Things"*

Any questions?

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