Preventing Failures in Isolated Phase Bus

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The isolated phase bus (IPB) is a high energy system used to connect large electric generators to the power grid through the GSU transformer. A typical bus operates for decades with minimum care. How it works and how it is built is not common knowledge.

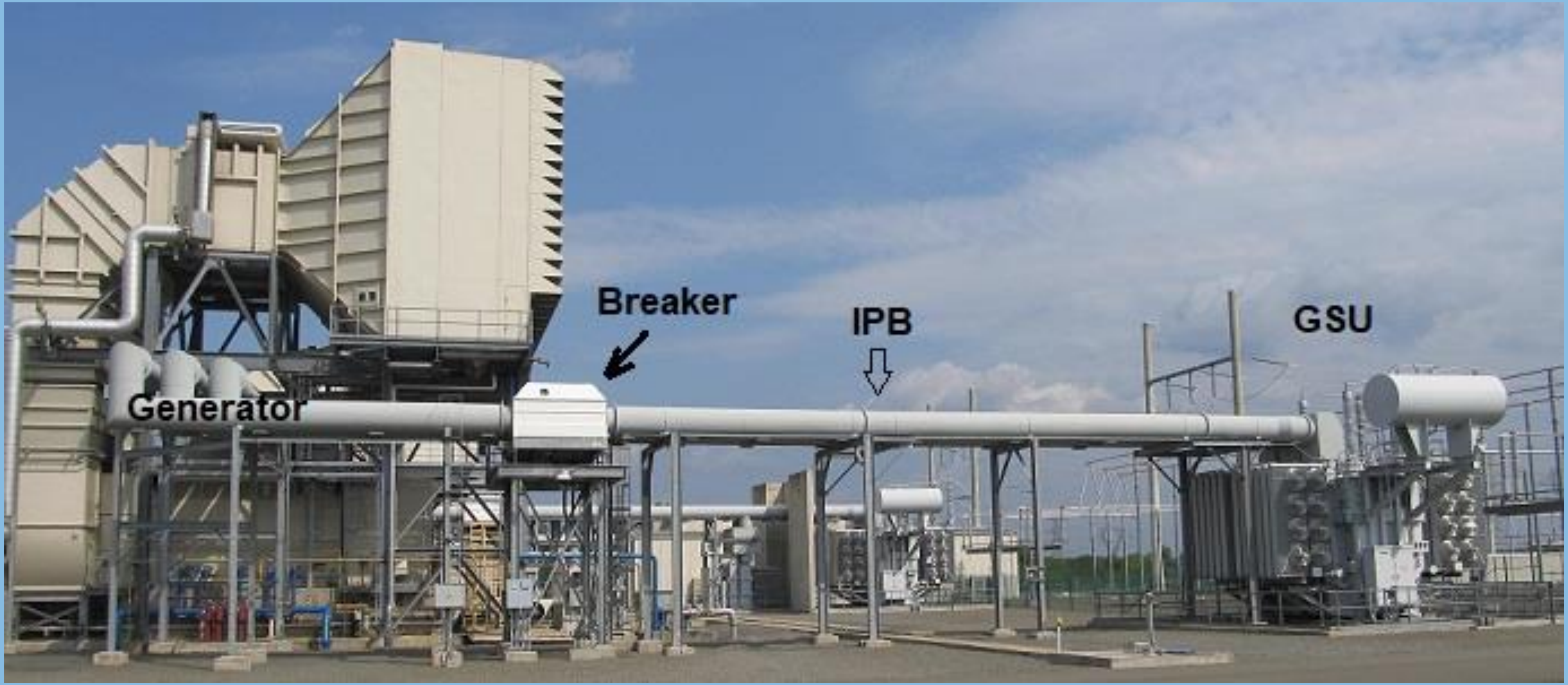
Because of inherent high reliability, these high energy systems are often ignored until there is a failure. Repair costs and lost sales revenue can run into millions of dollars. Collateral damage to a generator or GSU transformer can result in outage lasting up to a year.

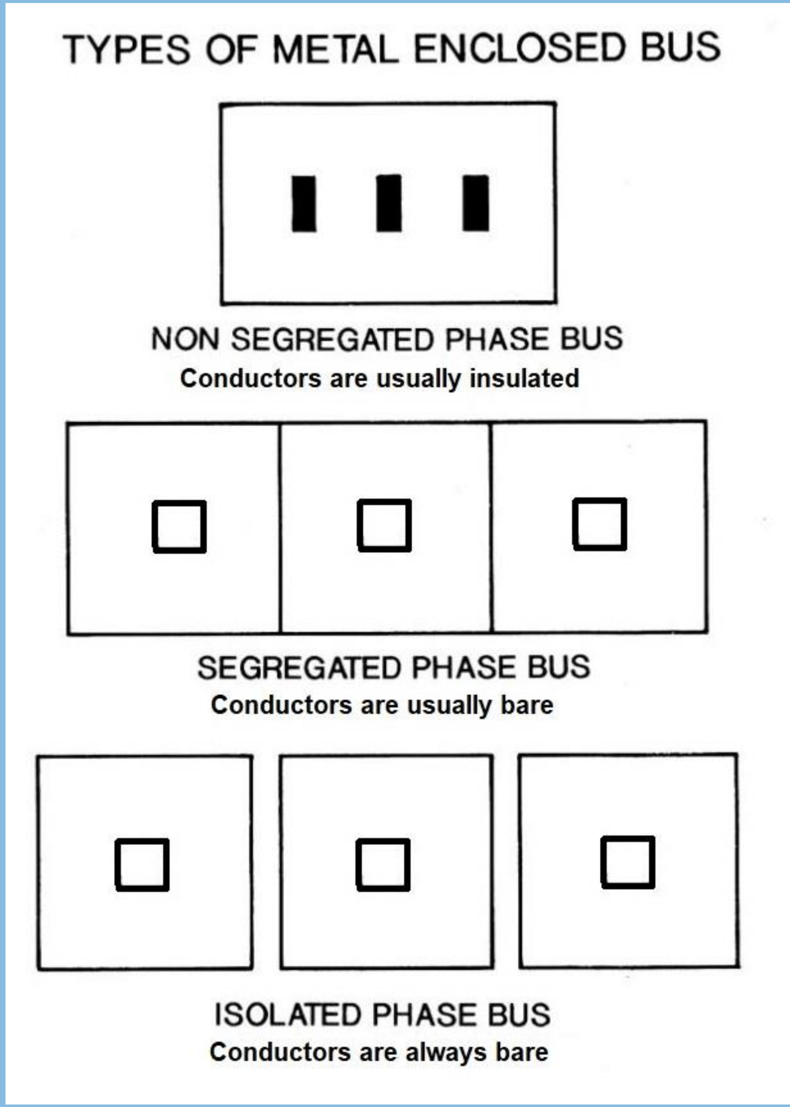
This presentation will discuss the more common IPB design features and a brief theory of operation. Typical failures and deterioration modes are discussed. Most failures can be prevented with proper inspection, maintenance and testing. The following design improvements and successful remediation measures are a combination of over 40 years following IPB at hundreds of sites in many countries.

The following are suggestions used by others to solve their specific problems, they may or may not work for you as well.

If you have developed a unique solution please let me know.

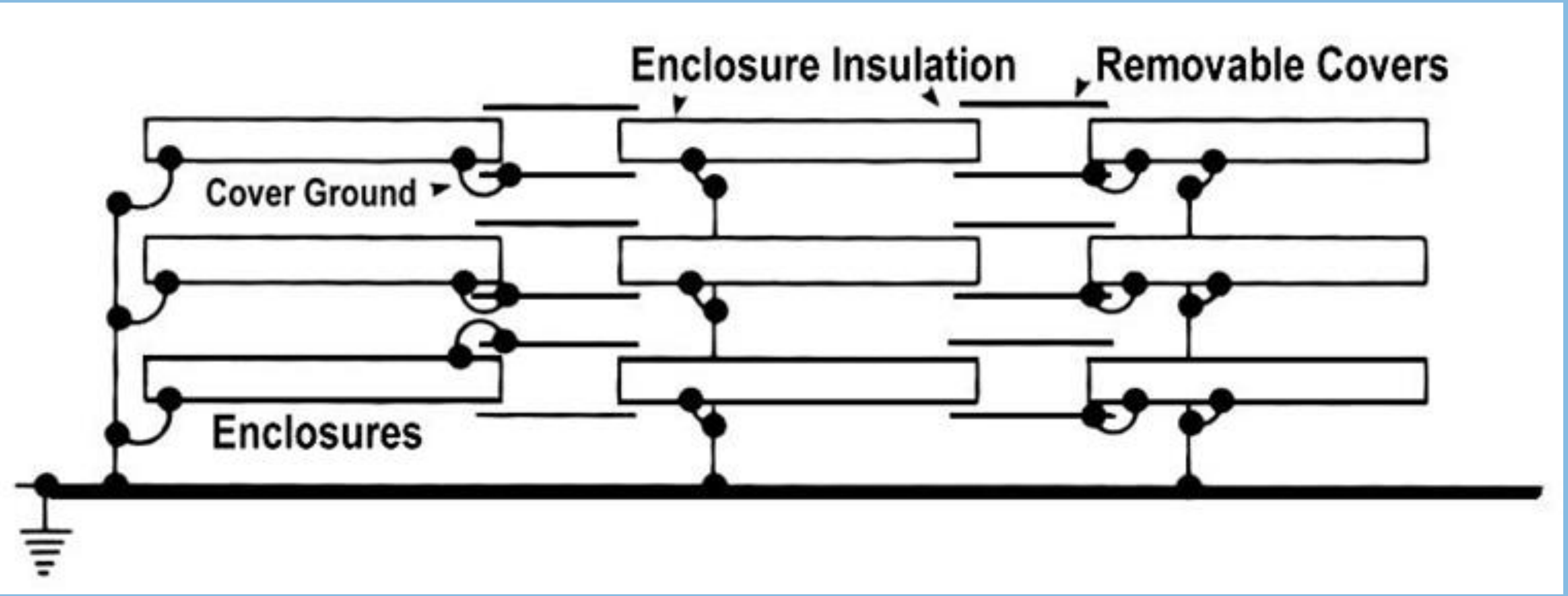
Typical modern isolated phase bus connecting a generator to the system. Perhaps 1000 like this have been installed.





There are several types of bus designs in use today. The non-segregated design remains popular for auxiliary systems with voltages below 15 kV and currents below 5,000 amps. Phase to phase faults will develop. The segregated phase bus helps but a fault arc often burns through the enclosure. The isolated phase bus design, with an air gap between enclosures eliminates this burn through and the incidents of a phase to phase faults greatly reduced.

There are two types of isolated phase bus depending on enclosure construction. The first, had non-continuous enclosures. The non-continuous bus enclosures consist of several insulated tubes. Each tube has a single ground location. This reduces the chance of a phase to phase fault, reduces stress on insulators during a fault and reduces external magnetic fields. The enclosure insulation will age and fail. Many remain in service today.



The non-continuous bus enclosures are insulated from each other and then grounded at one location.

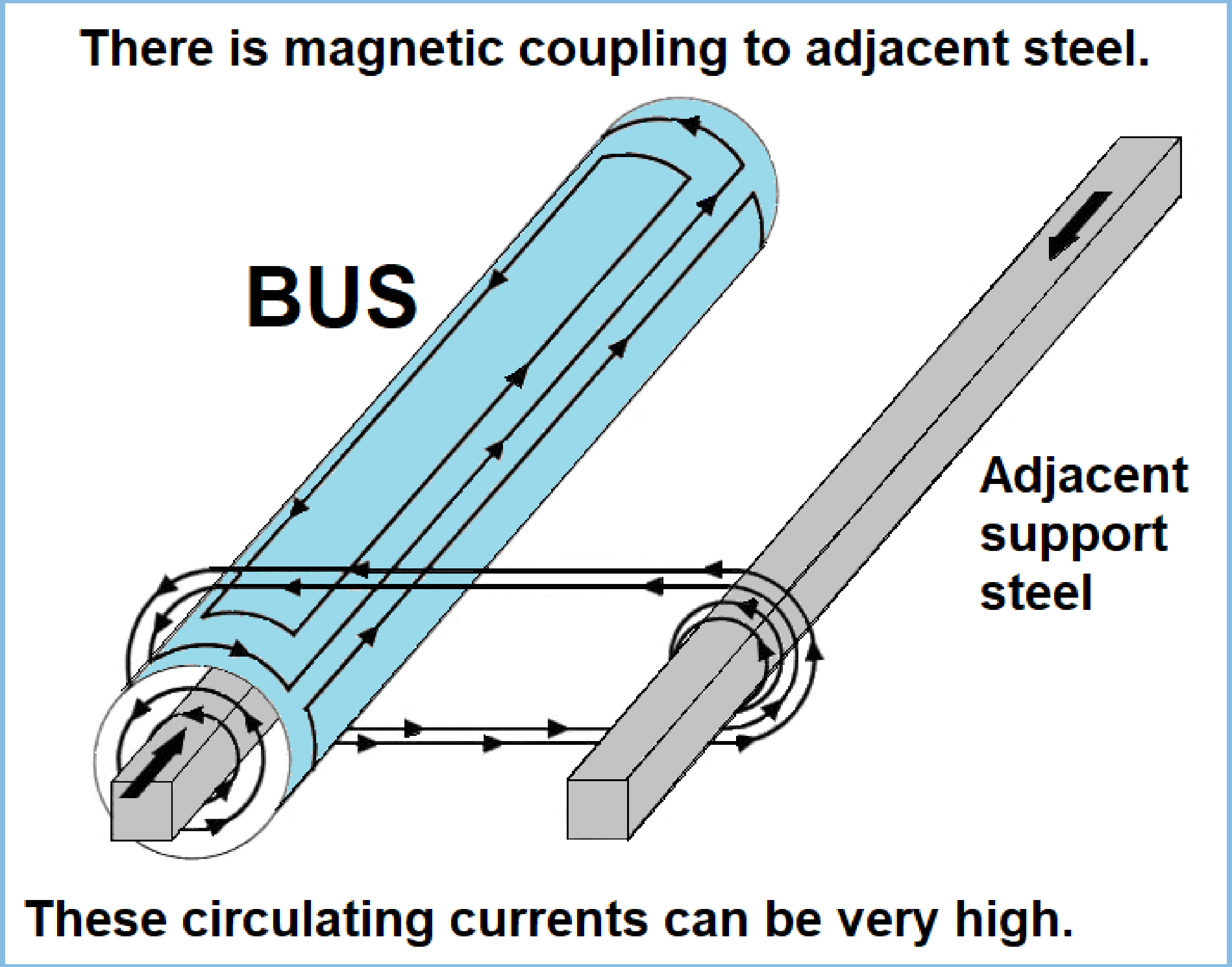
A large strap bonding adjacent enclosures is a feature of this design.

Note the straps connecting penetrations at the floor.

Circulating currents are induced into the enclosures reducing the external magnetic field by 30%.

The remaining 70% flux induces circulating currents in adjacent metal.

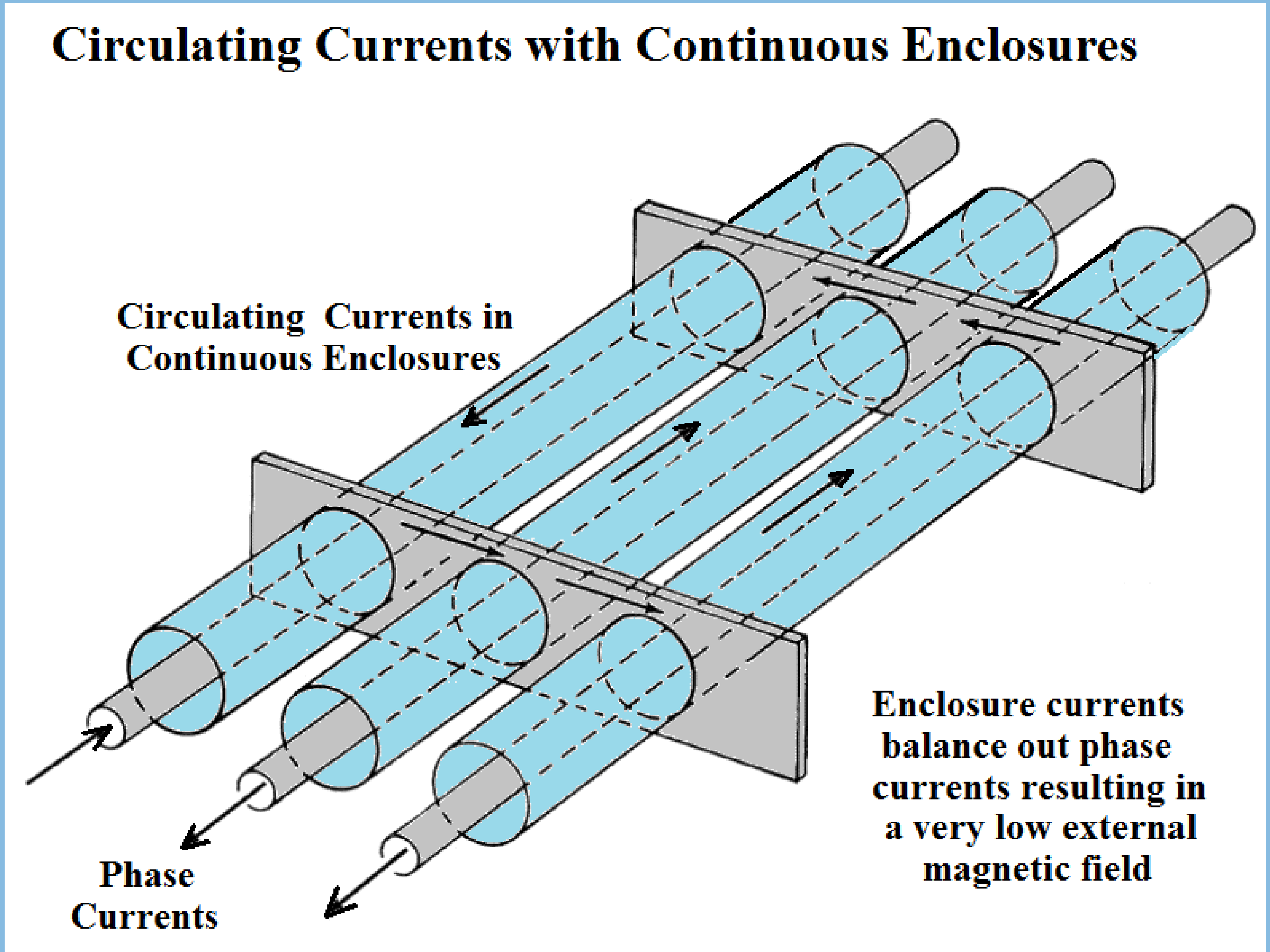
This became a serious problem when bus currents exceeded 15,000 amps.



The continuous enclosure isolated phase bus design solves this stray flux induced current problem.

A key feature are massive enclosure shorting plates at both ends of the bus.

Modern designs carry over 36,000 amps.



With a continuous enclosure design the external magnetic field is reduced by 95%.

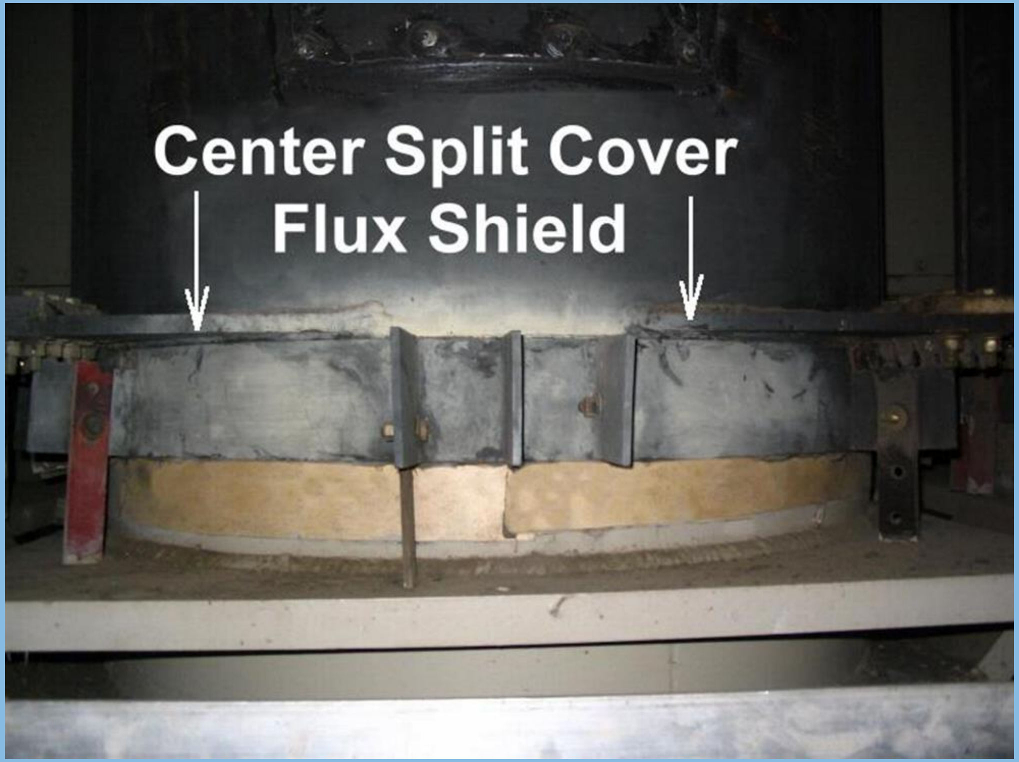
The shorting plates located at both ends, tie all three enclosures together.

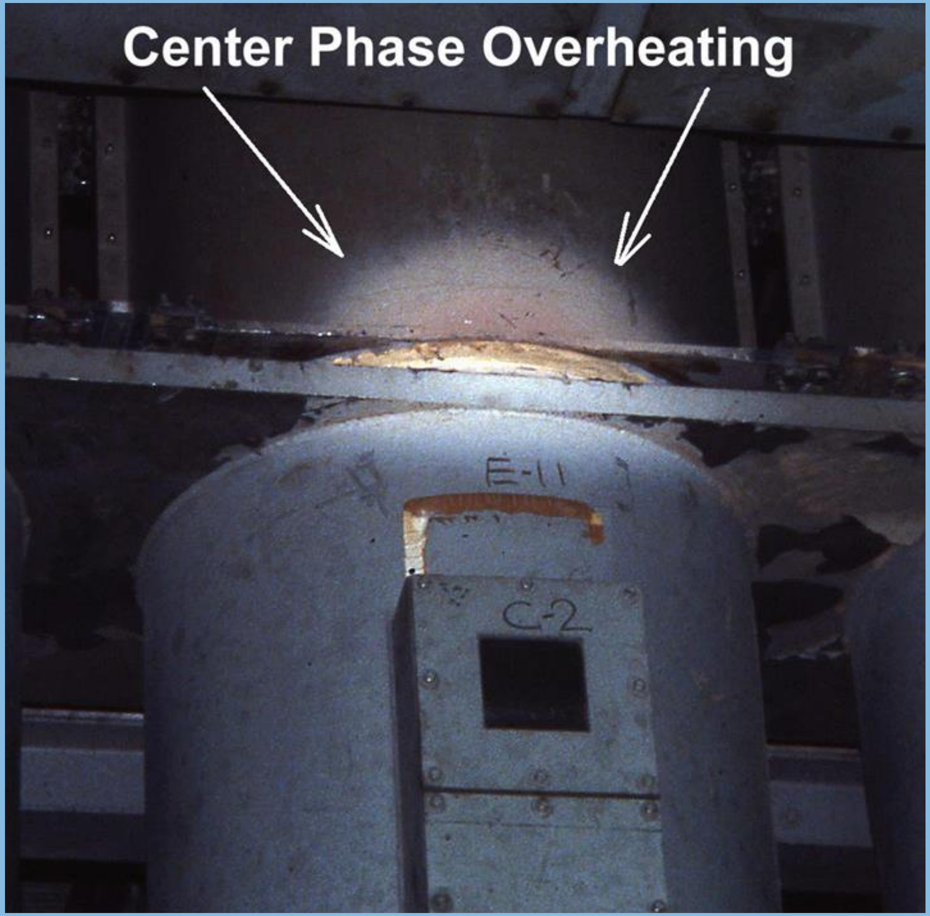
Insulator stress during a fault is greatly reduced.

There may be deficiencies in the original design. Below is a 30,000 amp neutral bus that needed more cooling. Note the severe paint oxidation. This extra heat will severely age the generator bushing current transformers.

The solution was to add new top ventilation holes. At some locations a fan to move air was found necessary. Free air movement under the generator is often restricted. A small increase in air movement can greatly reduce temperatures.

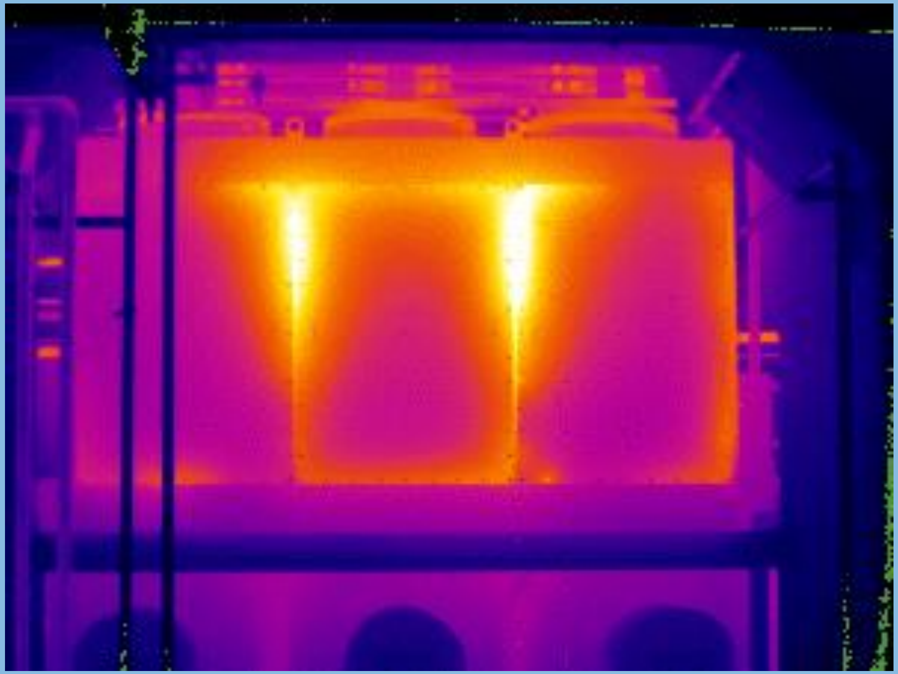
The center enclosure develops 50% of the total bus loss. Forced cooling is often required. Sometimes a flux shield is required.



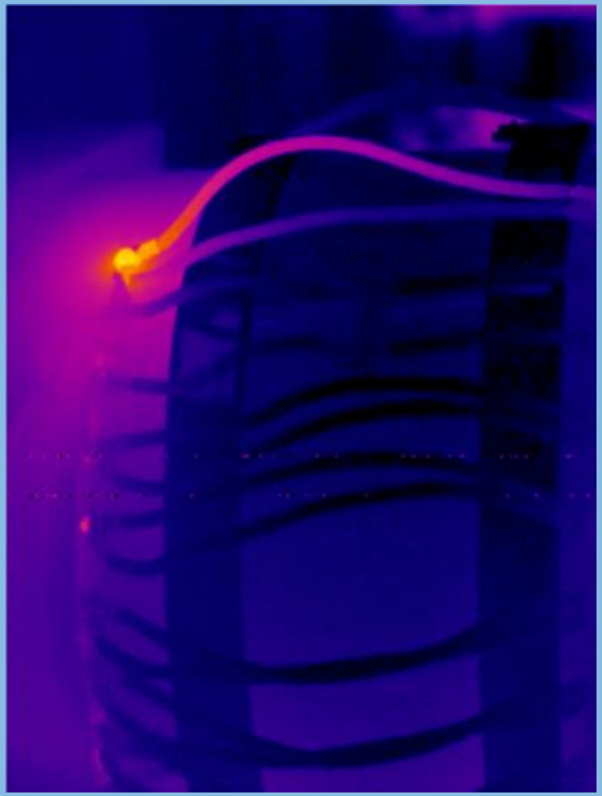


Measuring the flux direction will determine the source of heating and point to a solution.

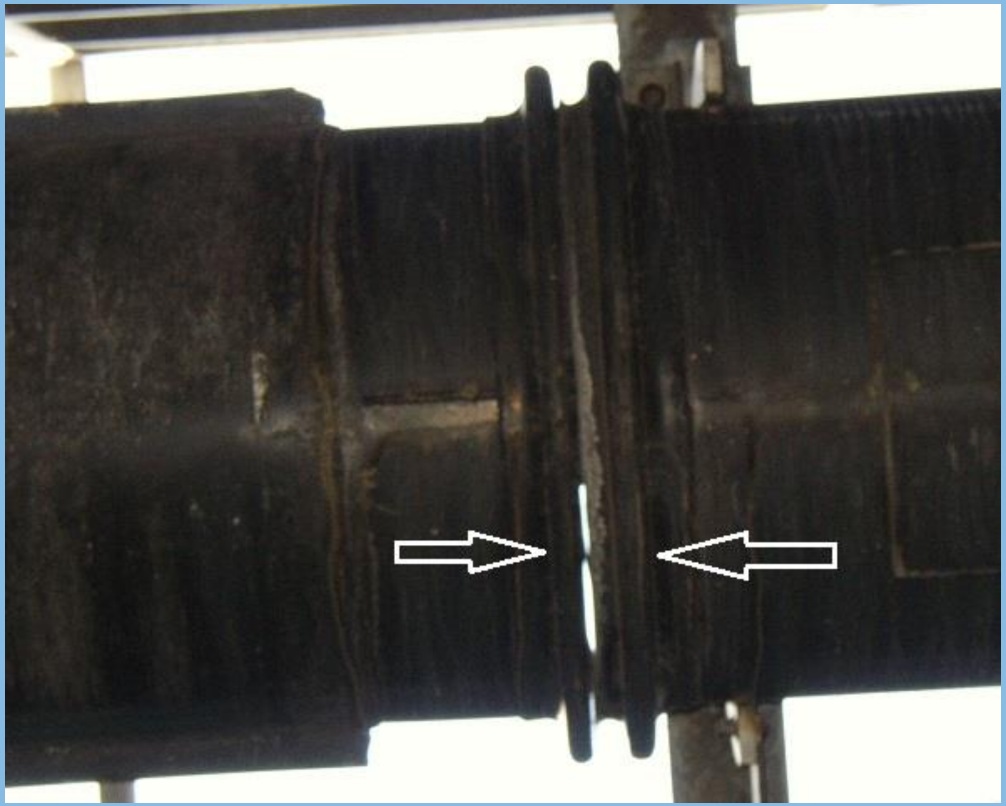
At this neutral cabinet, flux is perpendicular to the metal. A flux shield is needed, thicker metal, or improved cooling.

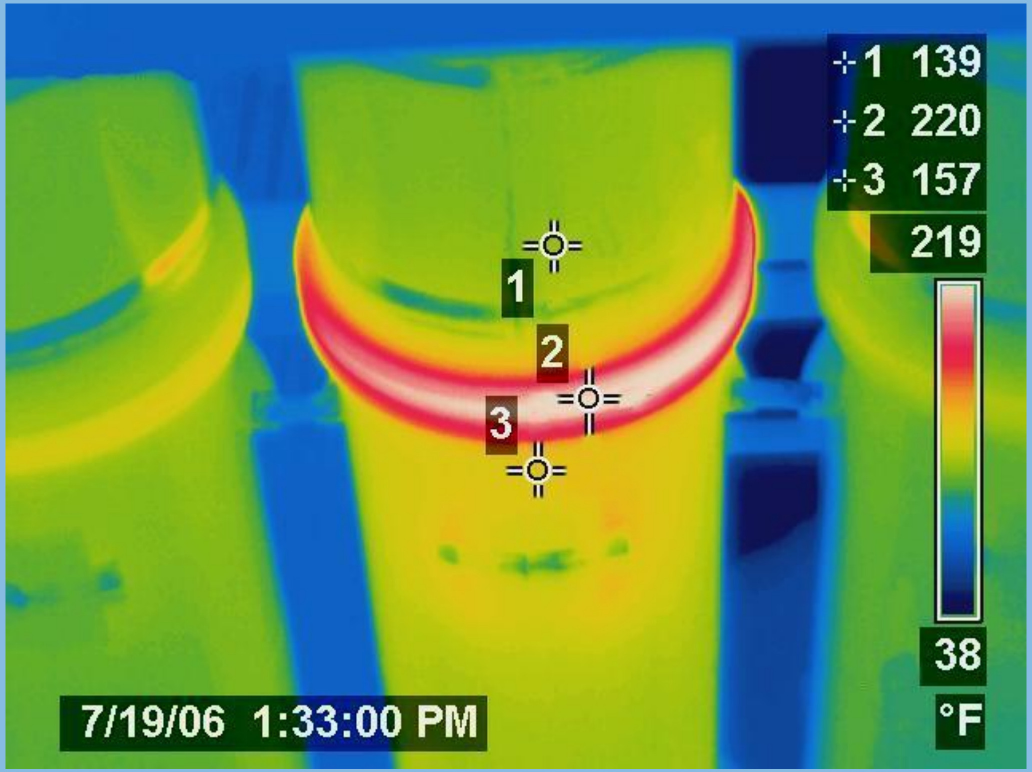


A visual inspection is critical for continued failure free operation. Infrared, (IR), confirmed one jumper was carrying most of the enclosure current, the cold ones were floating. To solve the problem on the right a new jumper design was developed. Note the ones working had melted.



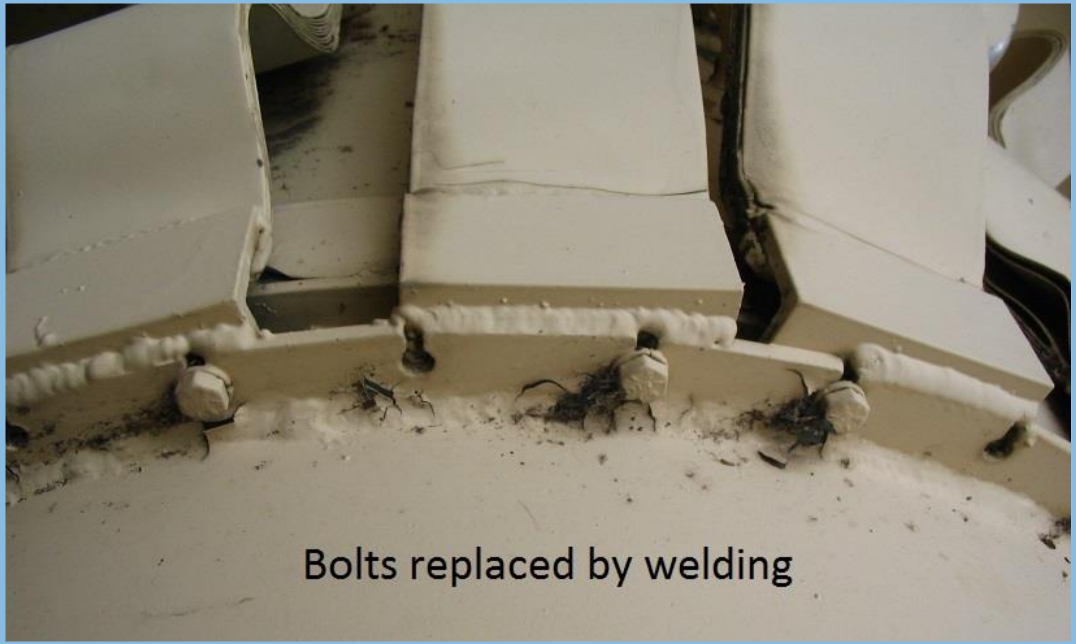
An IR scan of the IPB should be conducted every few months to locate hot spots and deterioration. This cracked enclosure was first spotted by IR. After 30 years of temperature cycling these cracks can be expected. Rubber expansion joints also fail.



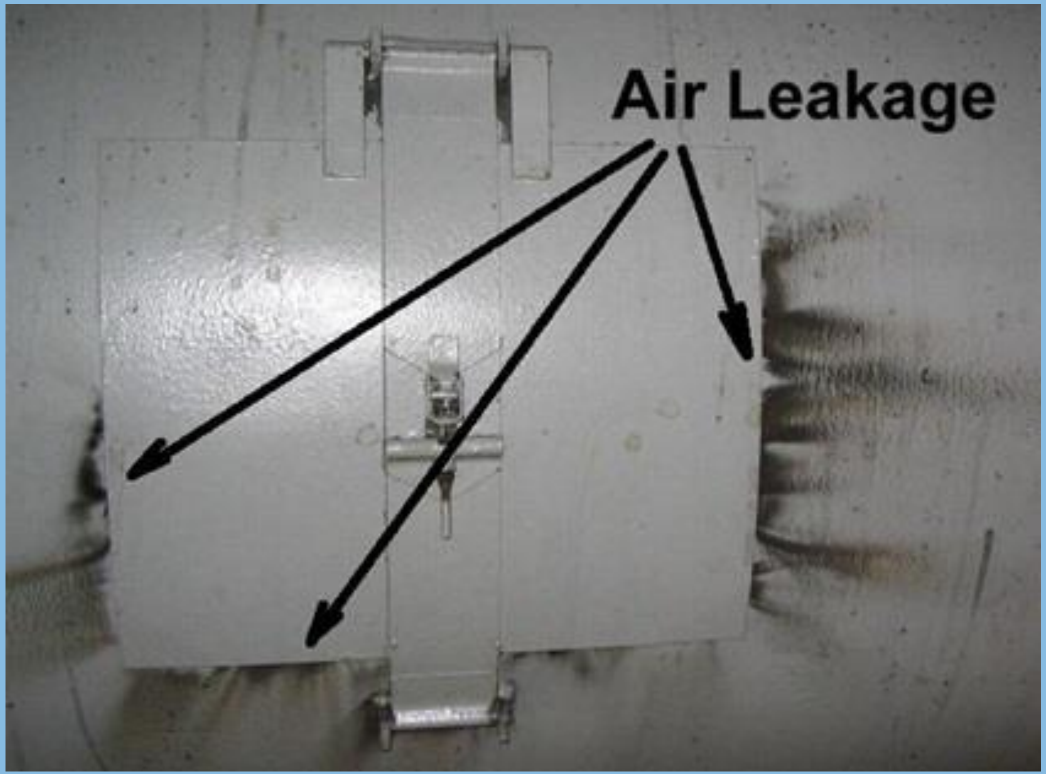


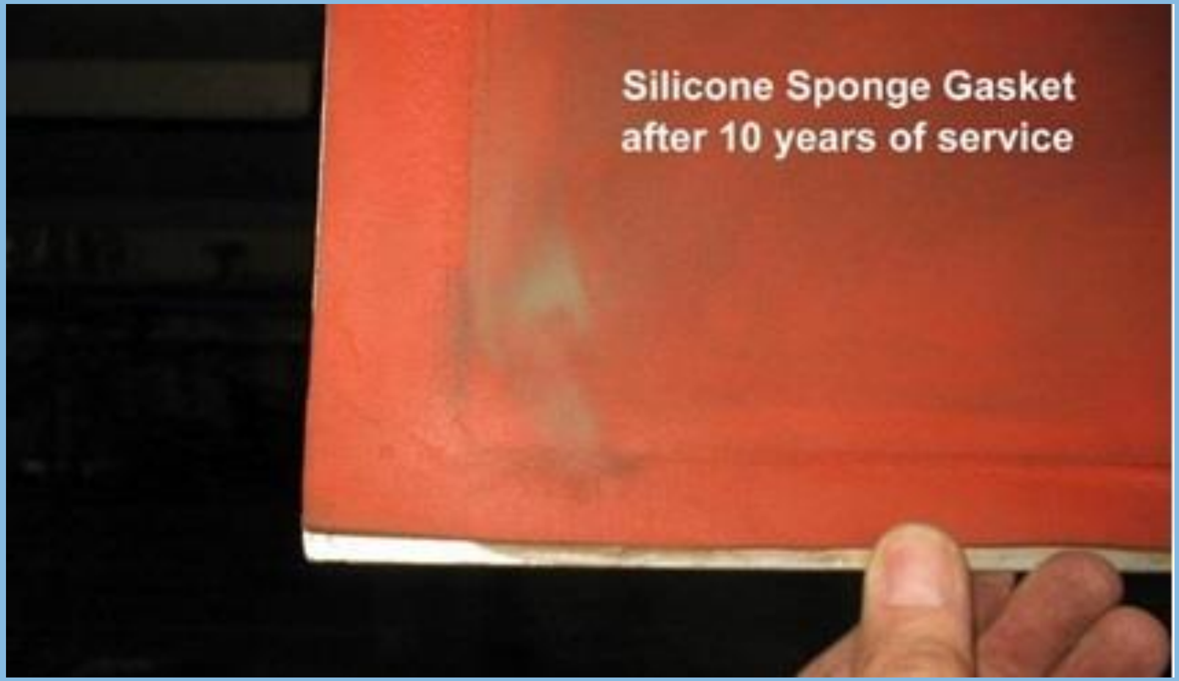
Some enclosure designs are difficult to maintain. Here the owner had to weld the enclosure shunts. The bolted surfaces were inadequate for both. Proper bolting will be discussed later.

It is amazing how few understand how to design a bolted joint.



Enclosure gaskets will harden and leak air or allow water to enter. The materials available to designers 30 years ago were limited. Replacement with new materials is necessary. Closed cell silicone rubber sponge is a lifetime replacement material.





IPB Standards include:

ANSI C37.20 or IEC (International Electrotechnical Commission) Publication 694

Isolated Phase Bus Temperature Limits

Enclosure	80°C
Conductor	105°C
Split Covers	110°C

Isolated Phase Bus Failure Temperatures

Aluminum to Aluminum Joints 70°C

Silver Plated Joints 105°C

Porcelain Insulators 125°C

Some designs can have higher temperature limits.

Detecting problems inside the enclosures is difficult. Infrared has very limited application in detecting center conductor problems. Partial Discharges, (PD) and electromagnetic (EMSA), techniques do have the ability to detect internal problems with both the insulators and the center conductor. Here a bus is scanned for radiated EMI.

Ultrasound can be used but internal reflections and attenuation with distance, from the source, can be serious limitations.

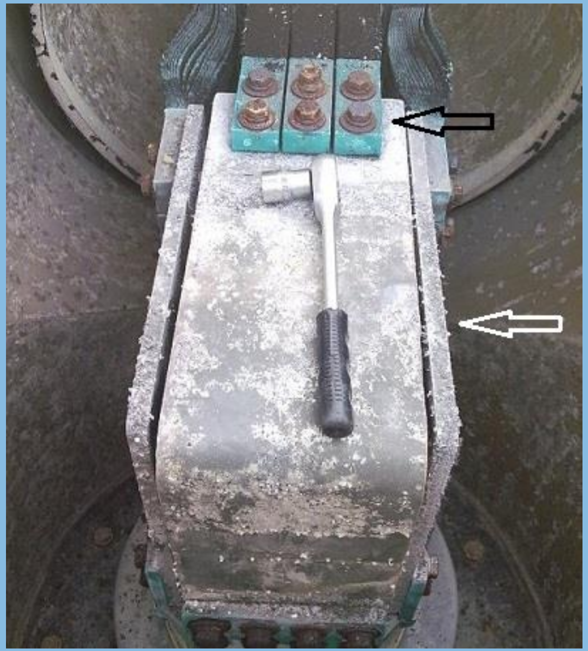
Visual inspection remains the best method.

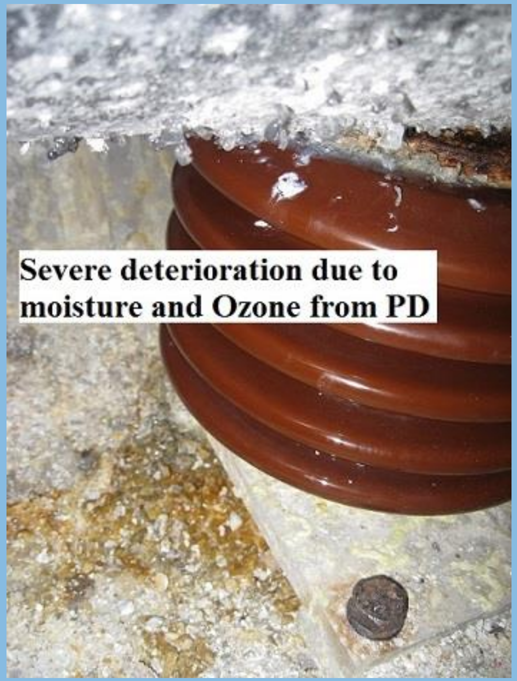
Insulators do collect dirt over time. Cleaning is necessary to prevent flashover. Many insulators are difficult to reach making this a multi-outage or continuous project. Some designs make removal for cleaning simple, others do not. Failure is more common when moisture is present and/or the dirty surface.

Isolated Phase Bus

An insulation resistance test @ 5,000 or 10,000 volts DC will detect wet or contaminated insulators. A minimum of 1 meg ohm/ kV can be used. Much higher can be expected on short, dry bus. A DC or AC over-potential test is the only suitable test to confirm continued insulation operation. Values should be higher than rated operating voltage. Most prefer the DC test due to the smaller test equipment size. A variety of values are used (75%) of the 100% test of twice rated voltage + 1000 volts, AC.

I define a “sealed system” as one that water enters but can not escape. IPB must be kept dry. Ozone and moisture form nitric acid which attacks all metal. Some systems are sealed and have a slight positive pressure of dry air. If maintained this works fine.





In very wet environments a roof over the bus or various components has been necessary to keep out rain. This also lowers operating temperatures by blocking direct solar heating.

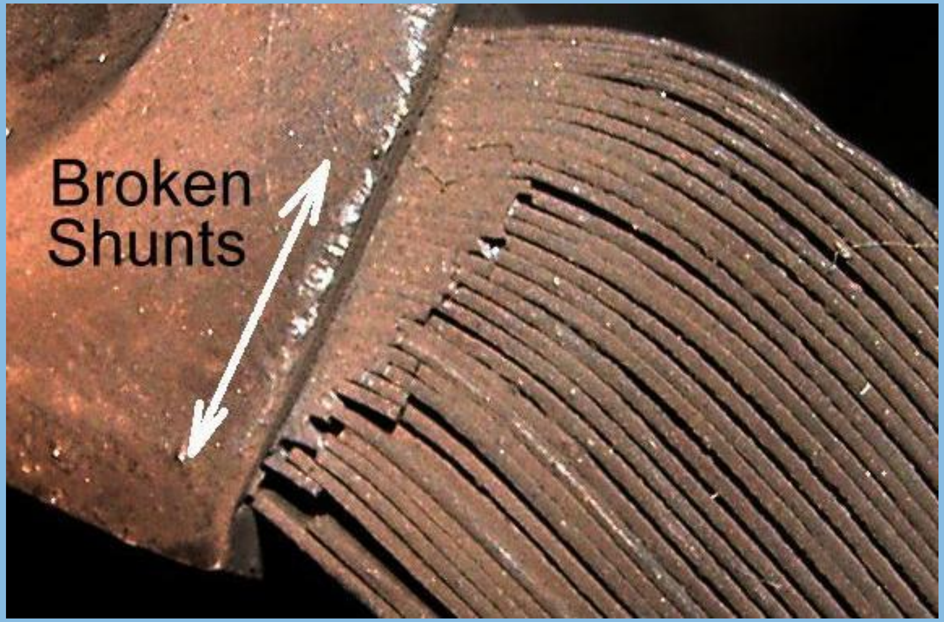
The examples below are from Malaysia, left and Texas, right.

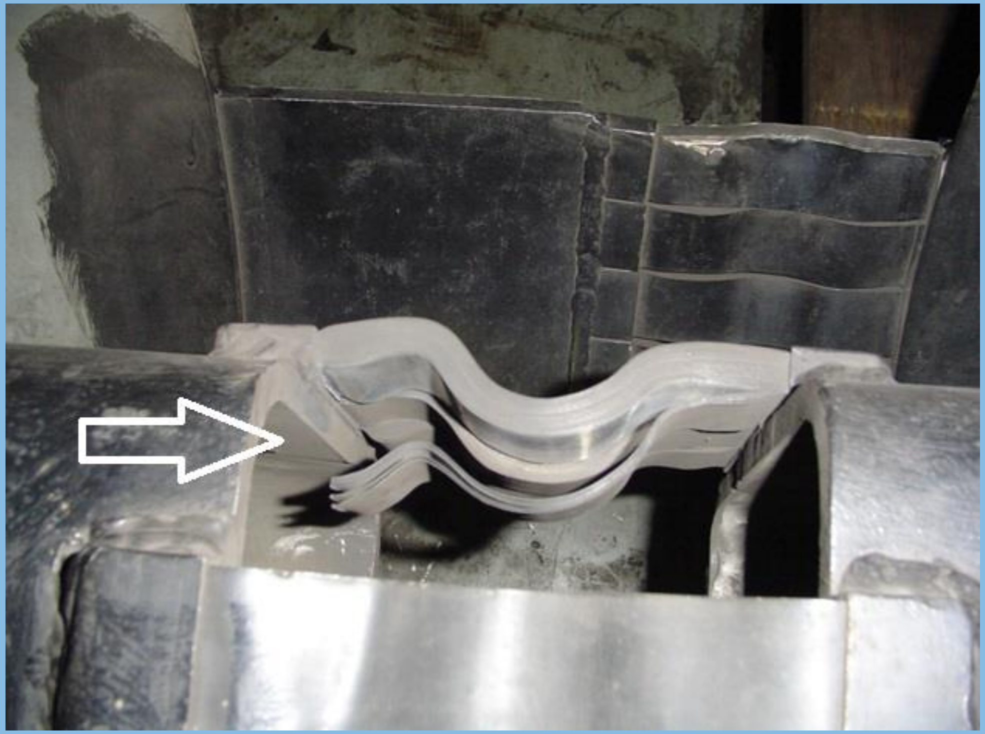
Here the main bus is fitted with a roof for weather protection.

Often the breaker needs protection from the sun and rain. Many have added a roof.

Non forced cooled IPB must have vents to reduce accumulation of fog and free standing water. Simple to install, and very effective in clearing moisture. Most bus have only water drains which will plug. The examples below are in Virginia and Malaysia. A screen to keep out birds and insects is mandatory.

Metal shunts to accommodate center conductor expansion are common. These may be copper or aluminum depending on the design. These thin leaves all work harden, from vibration or when flexed and crack.

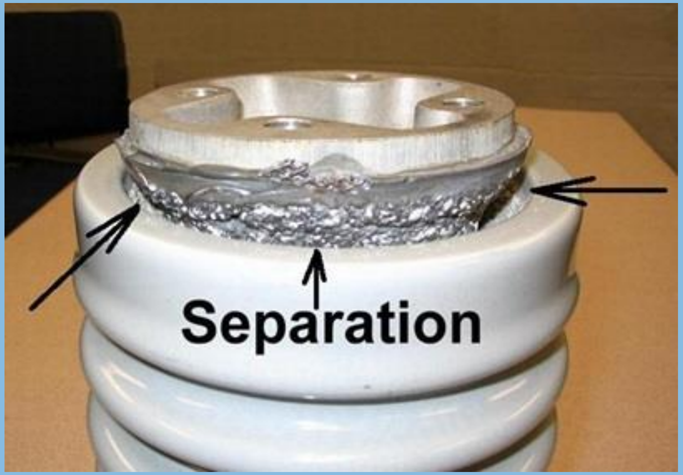


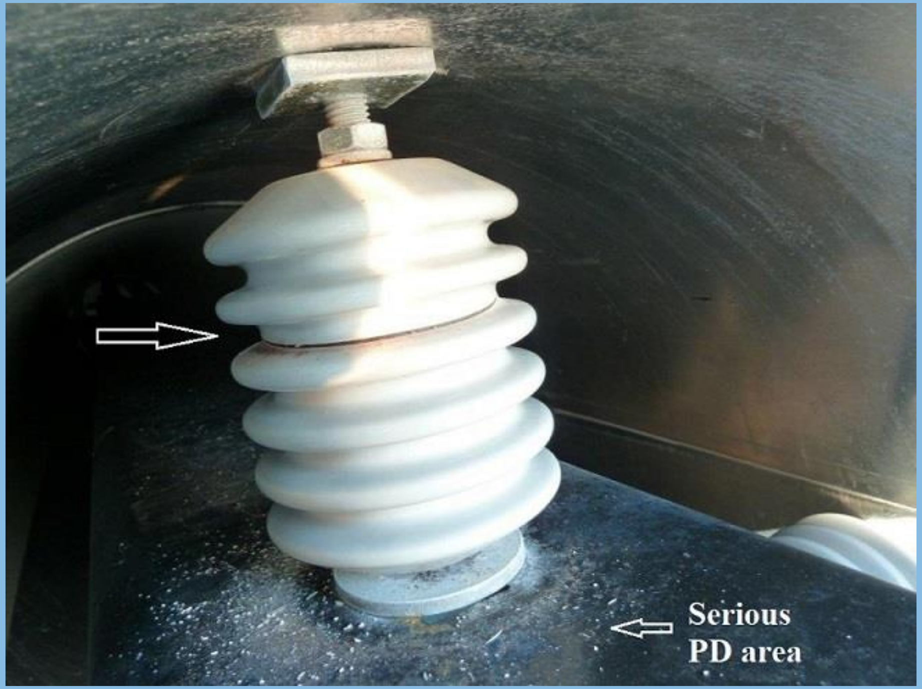


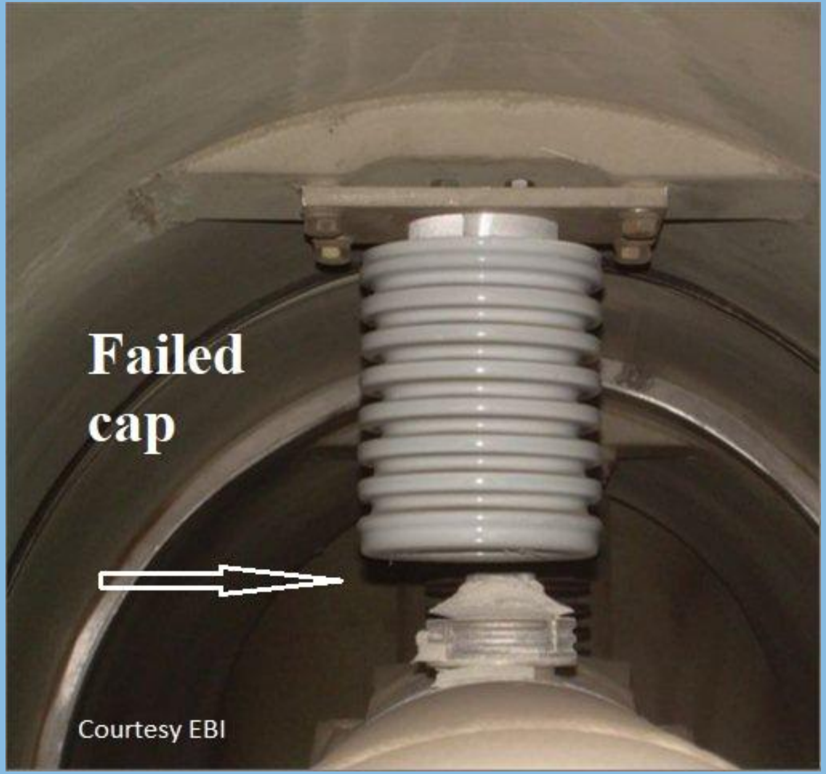
Thin metal shunts should be replaced with copper braids or ropes when possible. They are more resistant to vibration and flexing damage.

Broken and cracked insulators generate high levels of PD that is easily detected.

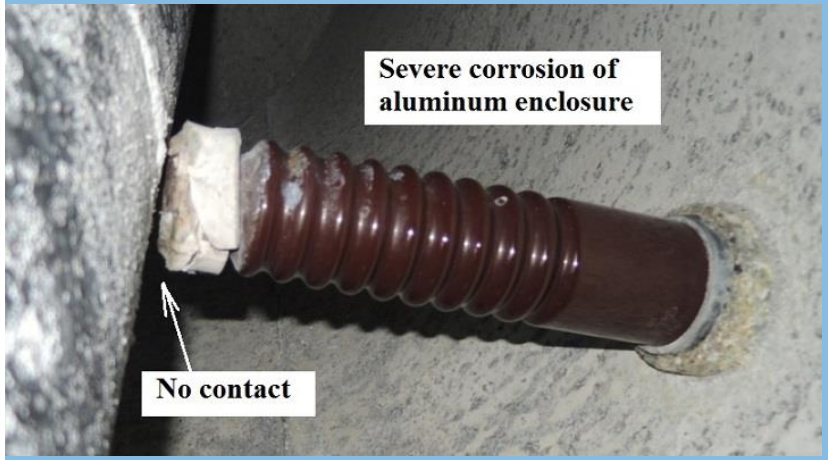
Several designs are prone to this deterioration. Try a different design.

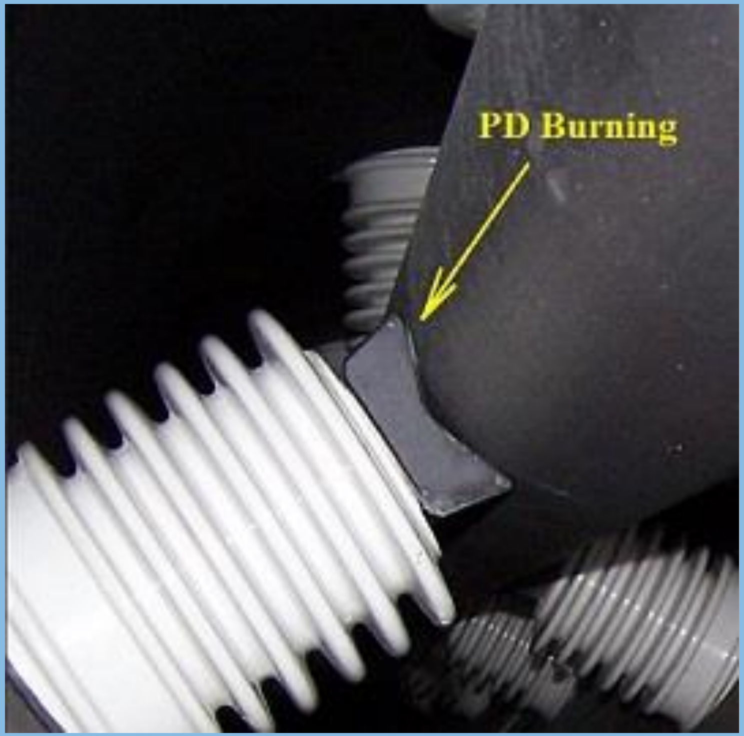




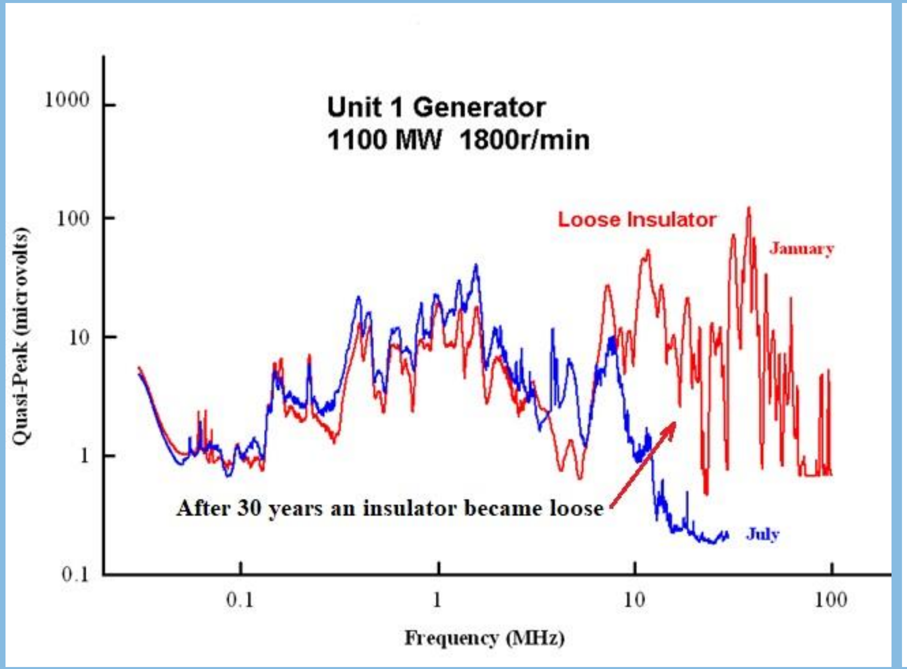


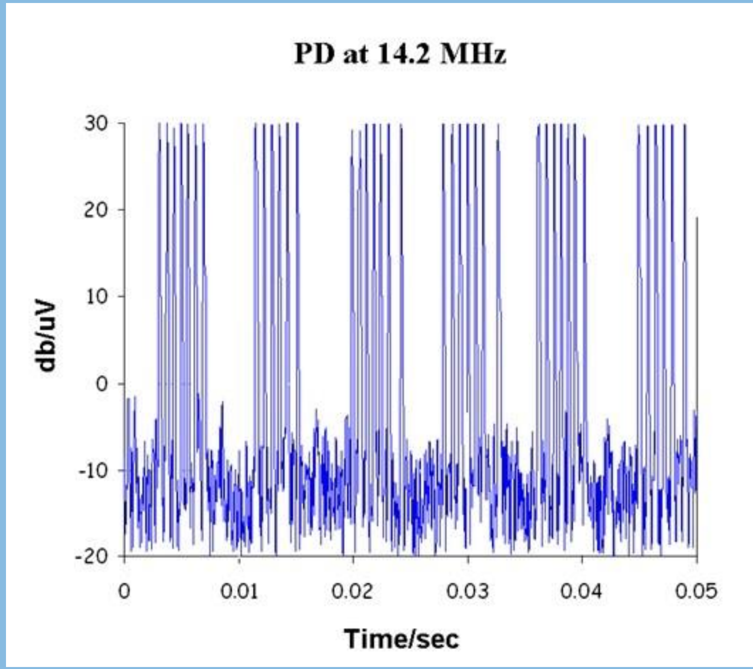
Insulators that are not in good contact with the center conductor generate high levels of PD. Many designs are prone to this condition. High PD results in high ozone levels.



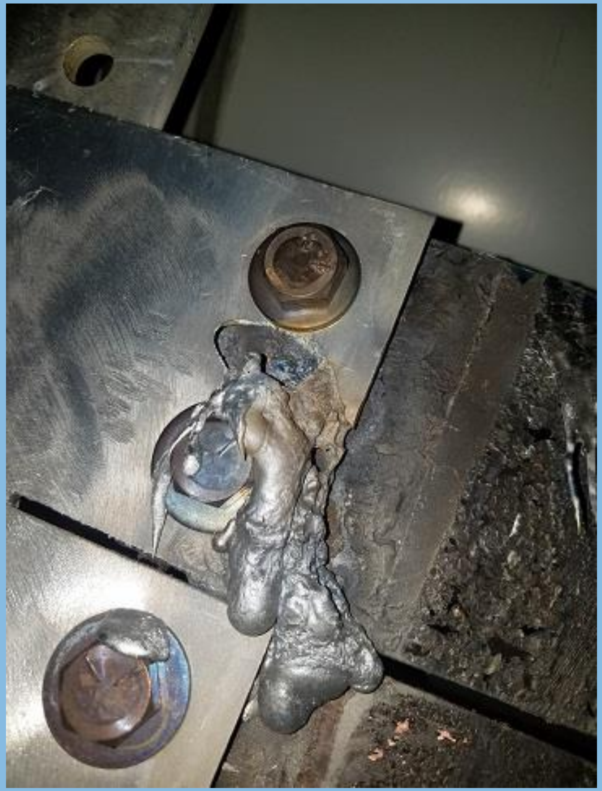


Insulator bolts can vibrate loose. Here is an example of the frequency domain EMI signature for this condition, the time domain PD pattern and the condition found.



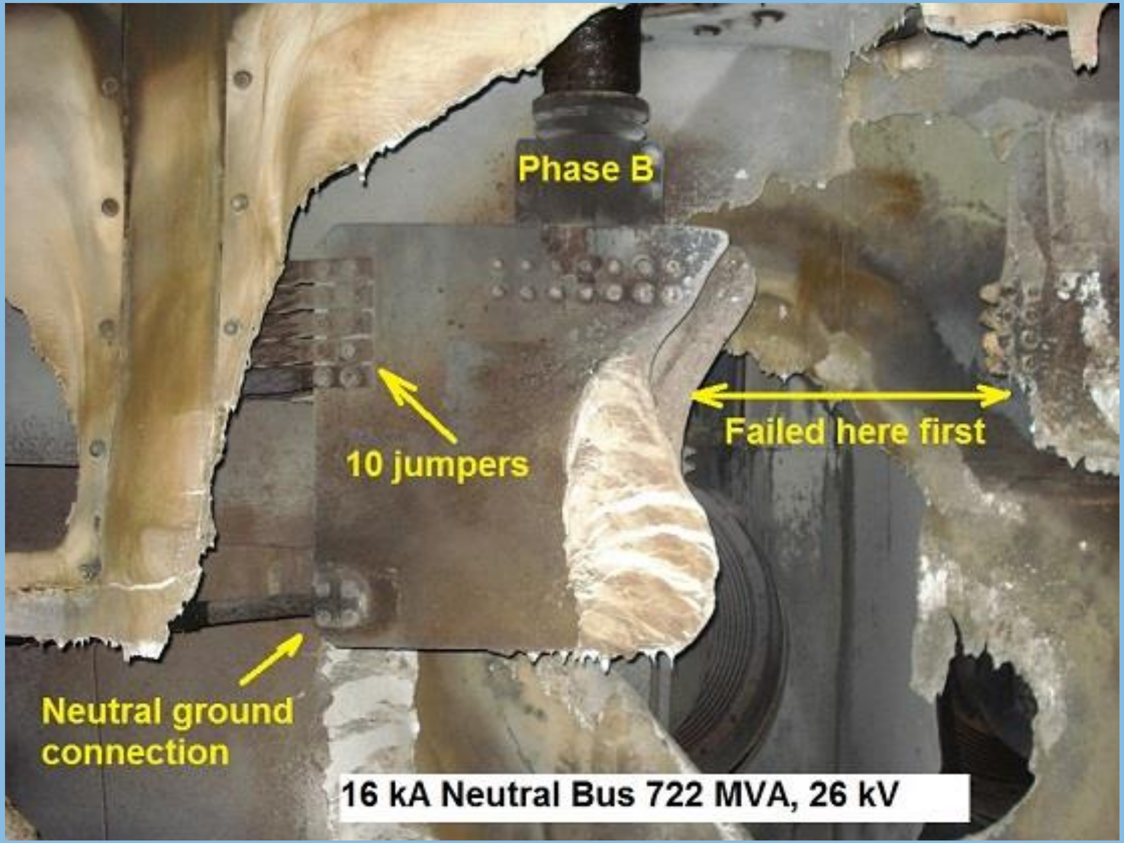


Lack of proper center conductor bolting is the #1 reason for bus failures. There is no excuse for not torqueing bolts correctly. There must be a written procedure to follow.

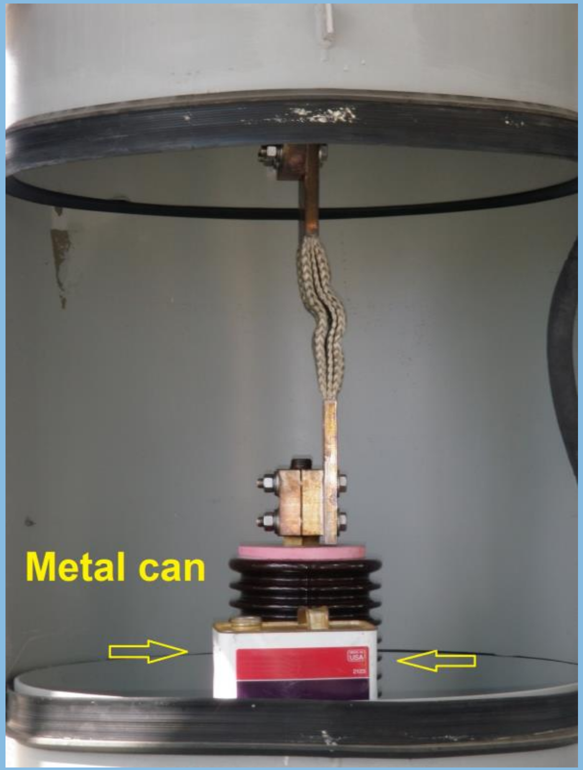


The procedure for torqueing should include torque specifications for the bolts and washers used, visual inspection of hardware, replacing Belleville washers after each use, second checking of these torques and hardware makeup by independent person (not on the job site when the first crew was doing their checks/torques).

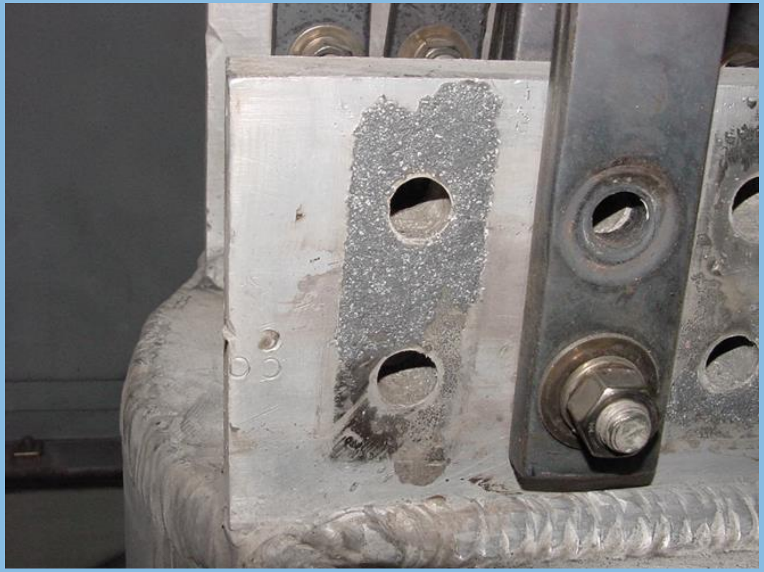
Be very careful when there is a change in the bus. Some mistakes are obvious. In the cases below too few jumpers were installed. The number of bolt pairs should be the same.

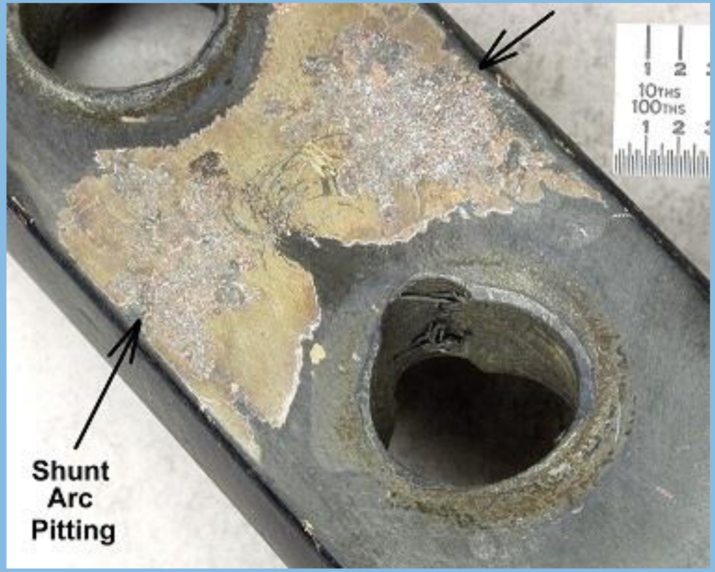


In most cases this poor bolting will result in very high levels of radiated radio noise or EMI. Metal objects left inside a bus will also result in high EMI levels. A scan for radiated EMI located the Foreign Materials problems shown below.

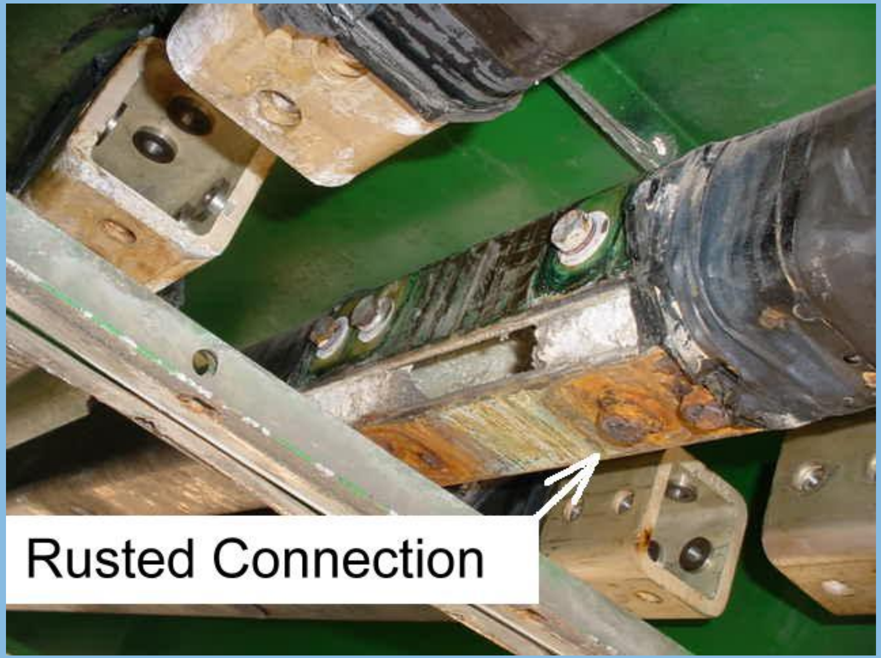


Poor contact will result in a cascade of increased temperatures, higher resistance and more heating until the joints melt. This is difficult to detect with IR, easy to detect with radiated EMI. IR will not see through the enclosure.

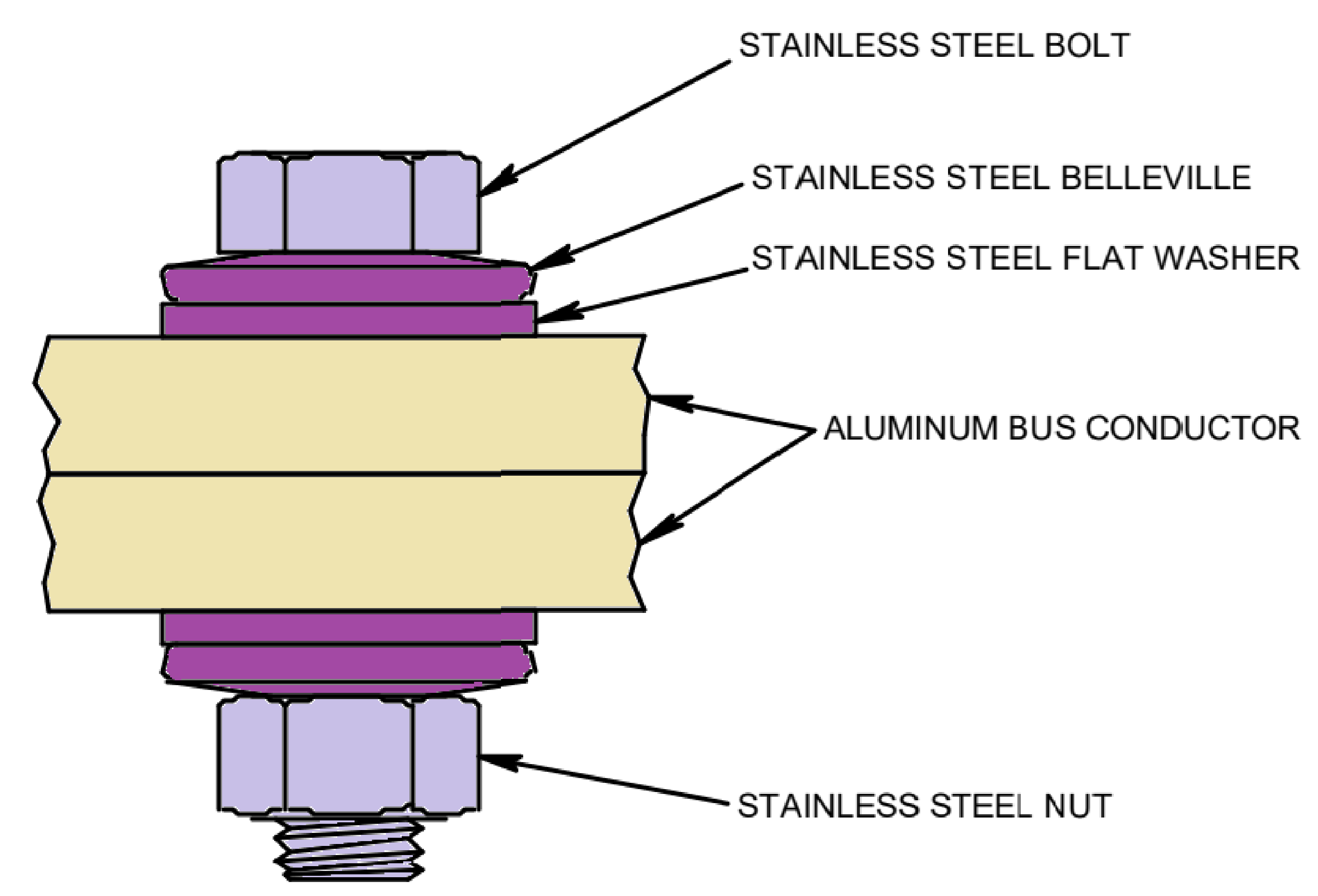




After almost 150 years it is amazing how few understand bolted electrical connections. The example below, left, shows damage to a copper conductor when incorrect bolting was used. Often lock washers and iron bolts are used to save money. Note the rusting below, right. The author has disassembled copper to copper joints with phosphor bronze bolts, still tight after 50 years service.

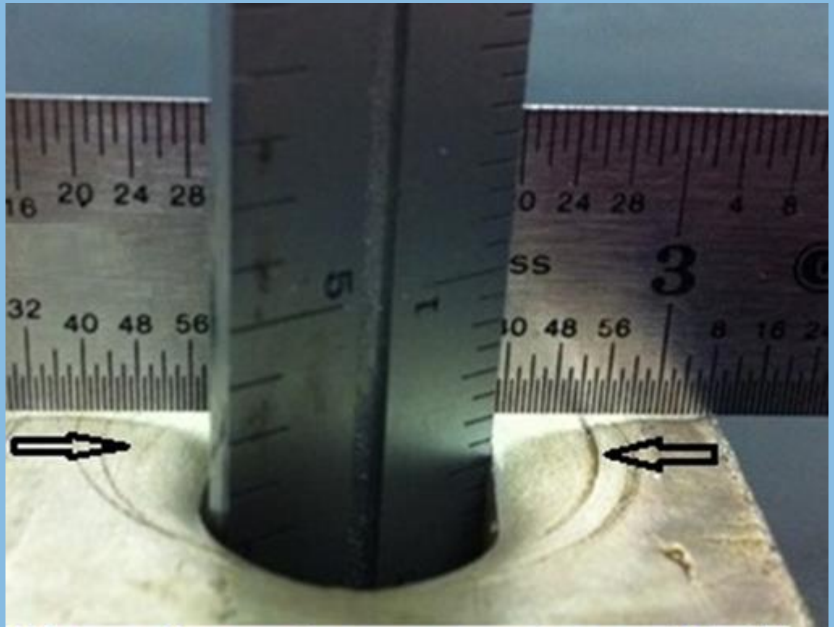


An excellent reference is, “Using Belleville Springs To Maintain Bolt Preload”, by George P. Davet, B.S.M.E. Solon Mfg. Co. This comprehensive paper describes the how and why of preload bolted electrical connections.

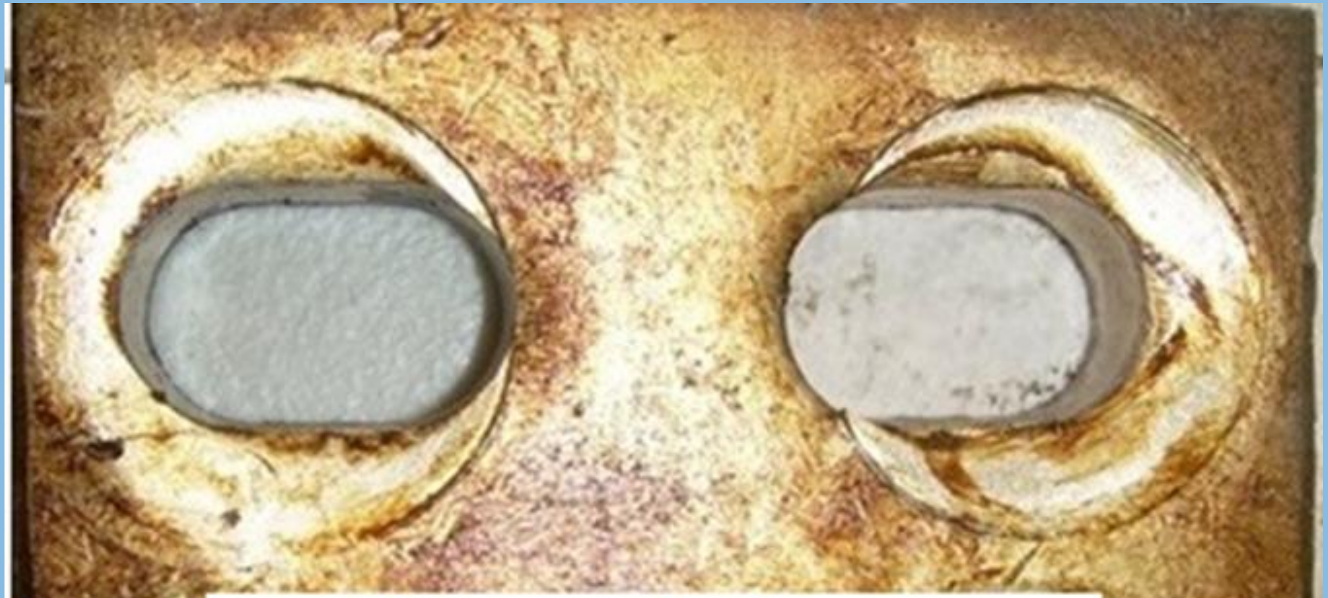


Properly made belleville bus joint

Electrical grade aluminum, EC, (1350) is very soft and will cold flow away from the pressure under a bolt if the correct washers and bolt torque are not used. Correct bolting of different metals will compensate for the differences in thermal expansion. Do not use split washers and iron bolts!

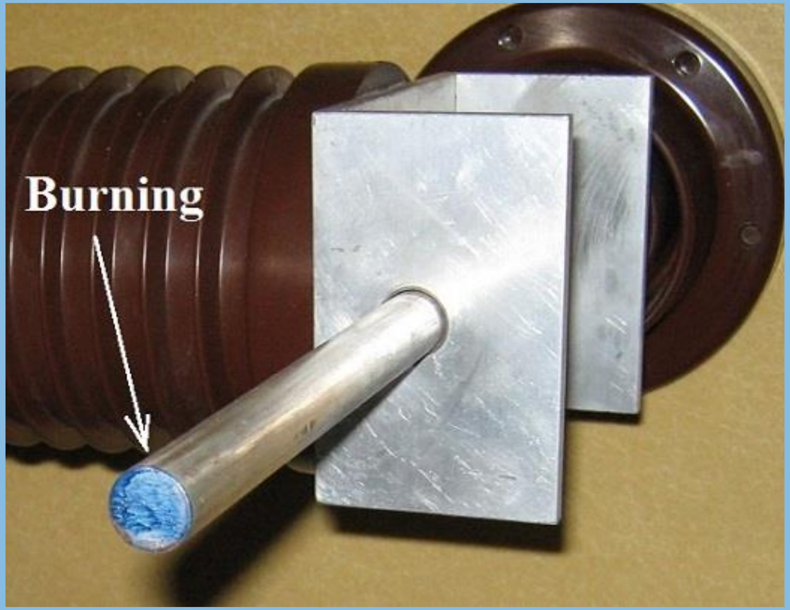


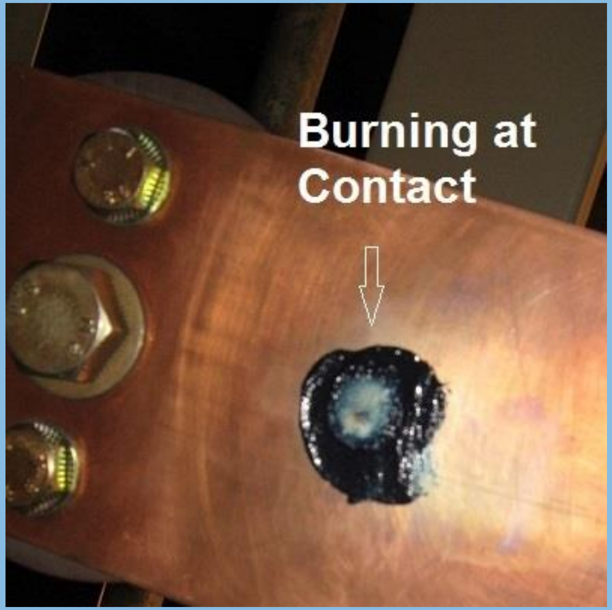
Distoration under an over torqued bolt


Cold flow of aluminum

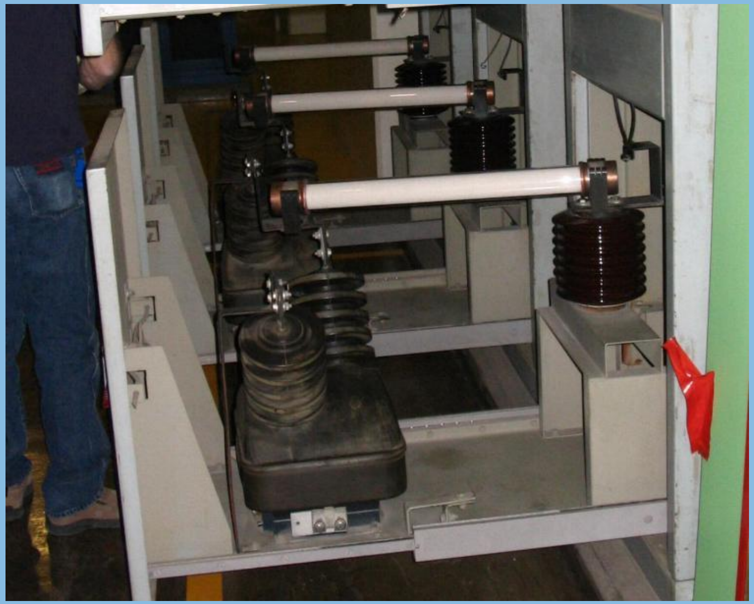
A location prone to deterioration is the potential transformer cabinets. Several problems are common to most systems. A scan for radiated EMI is an efficient method to determine if an inspection is warranted.

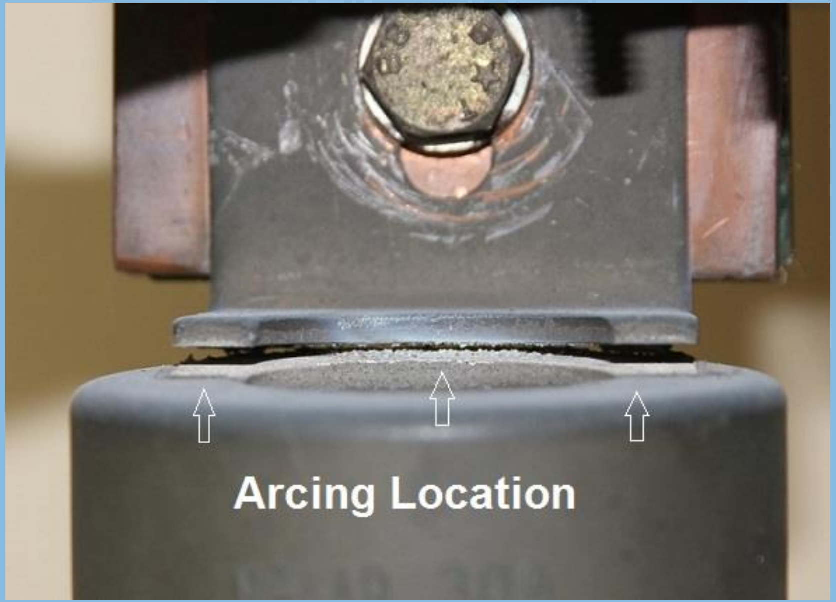
The design of potential transformer connections may not follow good practice. This one has no self cleaning wiping action. A high resistance contact results and arcing develops.





Deterioration of fuse links and connections is a frequent source of strong radiated EMI. Links open, clips break.





To prevent failures

1. Keep it clean
2. Keep it dry
3. Schedule visual internal and external inspections
4. Schedule IR and radiated EMI scans
5. Design out original defects and compromises
6. Always follow written procedures to bolt connections
7. Do not ignore minor problems, they tend to grow

1. Loose & broken support insulators
2. Contaminated insulators (dirt, cement dust, water, oil)
3. Loose and corroded bus hardware
4. Stray circulating currents outside bus enclosures
5. Defective isolated phase bus enclosure insulation
6. Foreign metal objects inside bus enclosure
7. Defective bus potential transformer connections
8. Open PT high voltage fuses
9. Loose AUX transformer connections
10. Loose GSU transformer connections
11. Defective surge capacitor connections
12. Loose disconnect switch components
13. Loose breaker connections

Summary

The isolated phase bus has come in many designs over the past 60 years. There are several major failures every year. Most designs require little maintenance for decades of reliable service. Routine inspections will correct most types of deterioration. Some modest design changes can be implemented to increase service life.

A valuable resource is the EPRI *Isolated Phase Bus Maintenance Guide*

TR-112784

Final Report, May 1999

It is now available to the general public.

Your bus deserves a better fate than this one in Ohio.

Thank you for your time

Questions ?

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