Inspecting
Isolated Phase Bus
For
Deterioration

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ABSTRACT

This paper discusses the basic design of isolated phase bus and how to identify several of the more common deterioration mechanisms through visual inspections, infrared and EMI measurements. Several examples are presented.

BACKGROUND

An isolated phase bus is that part of the power system that transfers energy from a generator to the main and auxiliary transformers. This bus consists of three large center conductors surrounded by grounded metal enclosures. With some designs the center conductors are copper but in most cases conductors and enclosures are round and constructed of aluminum.

A naturally cooled bus is larger and more efficient (larger conductor and enclosure, therefore less losses) than the forced-air cooled designs. Above 25,000 amps almost all isolated phase bus is forced-air cooled.

Two common designs are found in service, those with non-continuous enclosures and those with continuous enclosures. There are both common and unique deteriorations mechanisms for the two designs.

BASIC BUS DESIGNS – NON-CONTINUOUS ENCLOSURES

Many isolated phase bus built in the 1950's and 1960's are a non-continuous enclosure design. Each enclosure is made of numerous tubes or split sections. Each section is insulated at one or both ends, and grounded at one location, Figure 1. In operation there is a 30% cancellation of the phase conductor radiated magnetic field. Because of the remaining stray

magnetic field, all bus supporting beams are fitted with copper shorting rings adjacent to each phase enclosure to reduce stray circulating currents, Figure 2. The enclosure insulation must be in good condition or unwanted circulating currents and overheating of the enclosure and bus supports will result. The voltage induced from one end of an enclosure to the other is usually less then 5 volts, but several thousand amps can flow if the insulation fails. Enclosure operating temperature can be above 100°C. Thermal deterioration of original enclosure insulation is a common problem. The materials available today are much better than those available to designers in the 1950's, 60's or 70's.

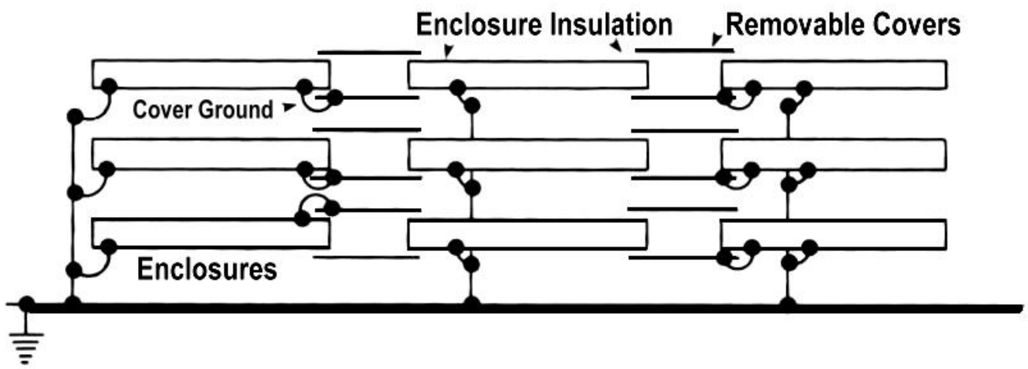

FIGURE 1: Isolated phase bus with non-continuous enclosures is a common design provided since the 1950's and remains available today.

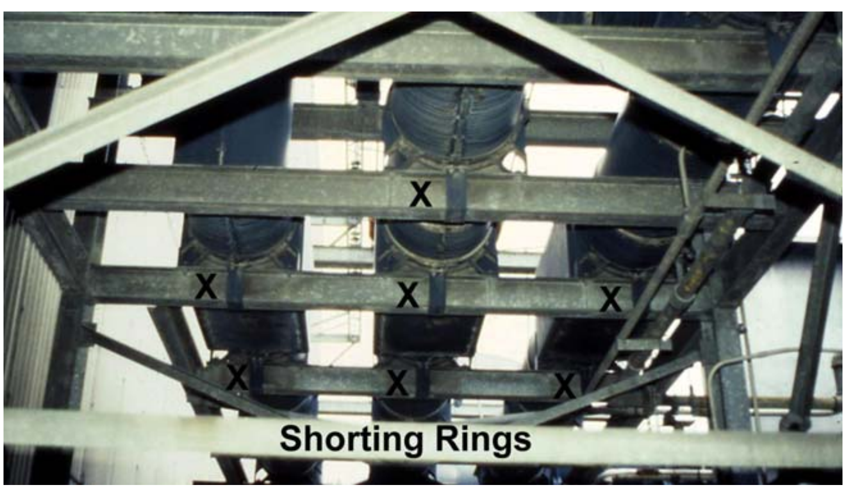

FIGURE 2: Copper shorting rings around the supporting steel under each enclosure is a positive indication the bus has non-continuous enclosures.

DETERIORATION MECHANISMS

The non-continuous isolated phase bus has deterioration mechanisms that can be classified into these general categories.

1. **Thermal deterioration due to operation at temperatures higher than the enclosure insulation system can safely withstand.**
2. **Mechanical stress from movement or vibration.**
3. **Contamination with dirt or moisture.**
4. **Marginal original design or material misapplication.**

Depending on the supplier, year installed and the design there may be hundreds of insulation washers, sleeves and gaskets. Replacement insulation materials can be expected to be a permanent repair and should be rated for 155 or 180^{o} C service.

Bus porcelain insulators are not designed to withstand vibration. Prolonged high turbine/generation vibration levels can result in broken bus conductor support insulators. Replacements will also crack unless this vibration is reduced.

Isolated Phase Bus must "breathe" to reduce moisture accumulation. If a bus is forced cooled, air leaks must be eliminated and the air makeup filters maintained. Repeated insulator contamination should be corrected to prevent insulator flashover.

BASIC BUS DESIGNS – CONTINUOUS ENCLOSURES

The continuous enclosure design, Figure 5, permits circulation currents in the enclosures surrounding each phase. These currents cancel around 95% of the magnetic field radiated by the three center conductors. Massive shorting plates at each end are a defining feature. No stray current protection of the supporting structure is needed between the two shorting plates. No magnetic shielding is provided outside the area between these phase-to-phase shorting plates and magnetic fields are very high past these shorting plates.

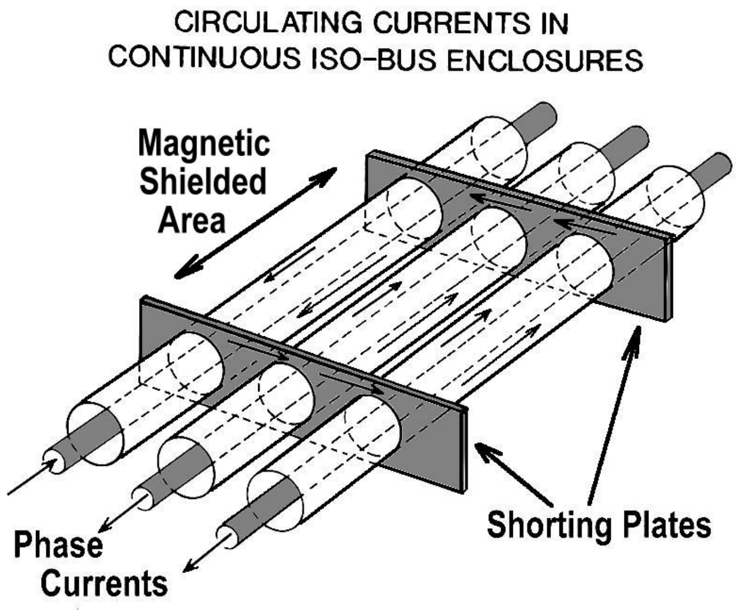

FIGURE 5: The continuous enclosure design has almost full phase current flowing in each of the three enclosures.

One method employed to provide enclosure continuity and allow for expansion is the placement of flexible straps from one enclosure to the next, Figure 6. These straps may be comprised of insulated cables or laminated shunts. Welded and bolted connections are used.

INFRARED INSPECTIONS

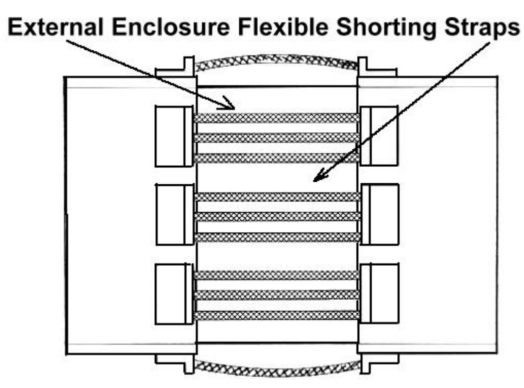

FIGURE 6: Expansion joint straps are welded to the enclosure in this design.

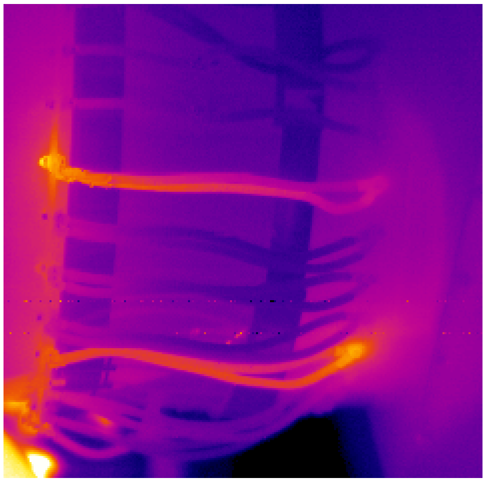

FIGURE 7: Infrared identifies deterioration of these bolted connections.

Routine infrared inspection along the full length of an isolated phase should be included as part of a good condition based maintenance program. The unequal heating of jumpers in Figure 7 indicates maintenance of several bolted joints is required. In this case the hot jumpers are the only ones carrying current. The cool jumpers have deteriorated high resistance connections and are not carrying current.

FIGURE 8: In some cases a visual inspection will located deteriorated external jumpers.

External strap type enclosure jumpers are a constant source of problems if not properly designed and maintained. The system in Figure 8 consisted of copper cables bolted to an aluminum enclosure with steel bolts and no contact surface plating. The conductors were sized with no capacity margin and the cable insulation was not resistant to operating temperatures or UV deterioration.

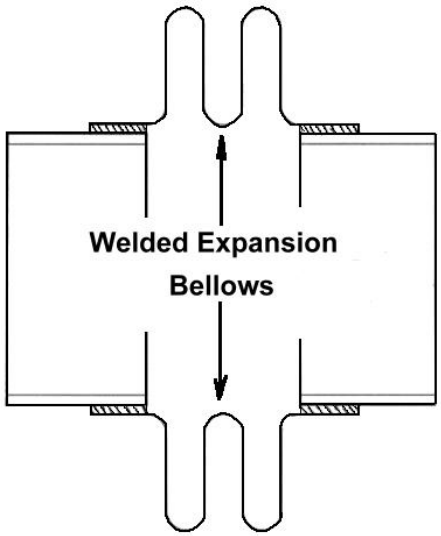

FIGURE 11: Another method to maintain enclosure continuity and provide for thermal expansion is the addition of welded flexible aluminum bellows.

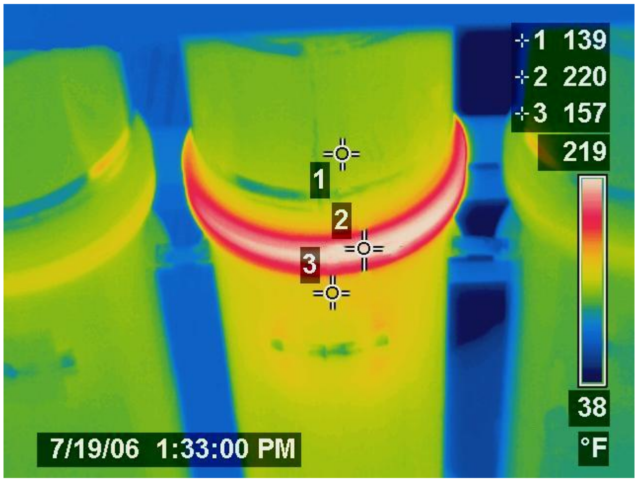

FIGURE 12: An infrared inspection of the welded bellows type enclosure expansion joints will detect any overheating resulting from age related cracks.

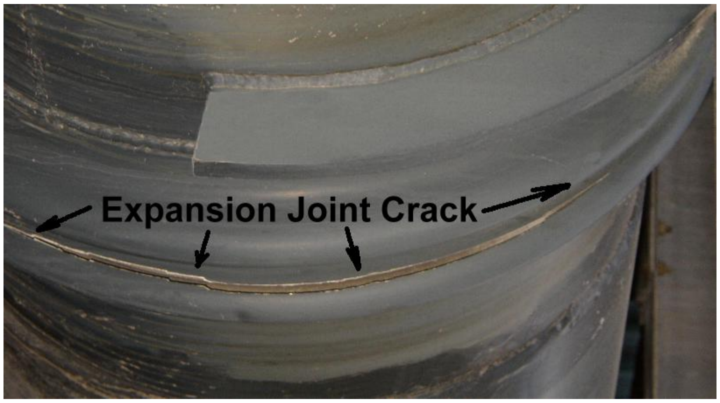

FIGURE 13: This crack is located on the opposite side of the overheating seen by an infrared inspection.

In general the welded type of expansion joints are more reliable than bolted designs. It has been noted that after 30 or more years of flexing these can also develop cracks.

EMI DIAGNOSTICS

EMI Diagnostics (electromagnetic interference) is another on-line test that can locate several types of conductor and insulator deterioration in isolated phase bus. The combination of IR and EMI will detect most types of bus problems. Defects in the bus conductors or insulators often generate radio noise that can be measured. The radio frequencies involved are usually very high and above those that are characteristic of generator or transformer related deterioration.

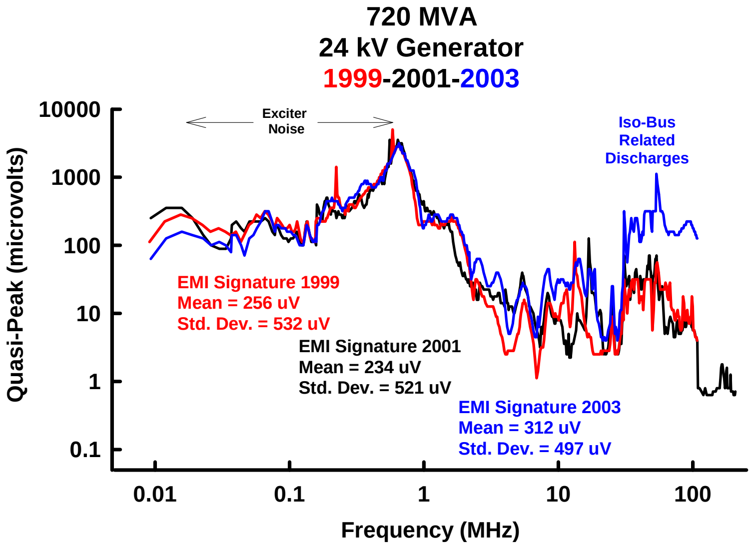

FIGURE 14: An EMI (electromagnetic interference) Diagnostic of the generator will detect deterioration of an isolated phase bus. Bus problems are seen at the higher frequencies.

Figure 14 shows the change in EMI signature of a large generator over several years. The 1999 curve (red) and the 2001 curve (black) are almost identical. The higher frequencies above 1 MHz increased in 2003 (blue). These frequencies and particularly those above 50 MHz describe the isolated phase bus. Measuring the radiated EMI along each bus enclosure will provide additional defect location information to focus an inspection on the correct phase and general location, Figure 15. An inspection was scheduled and the broken conductor shunts in Figure 16 were found. Rusty hardware, foreign metal objects, broken, loose and contaminated insulations have also been detected from on-line EMI Diagnostics.

FIGURE 15: A hand held EMI detector is used to establish the location of a defect.

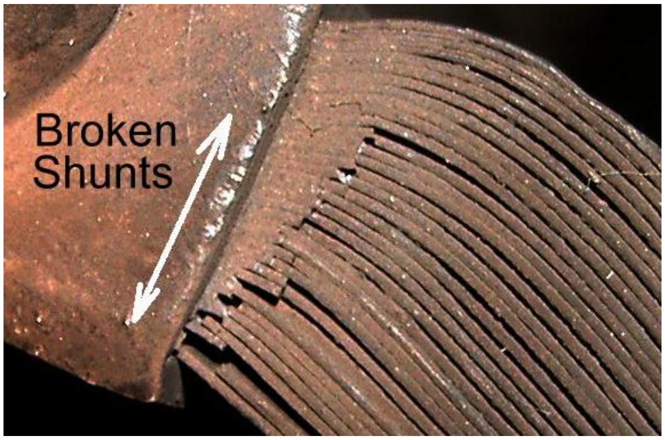

FIGURE 16: Broken shunts detected by the EMI Diagnostic. There was no external IR signature for this deterioration of the center conductor due to enclosure shielding.

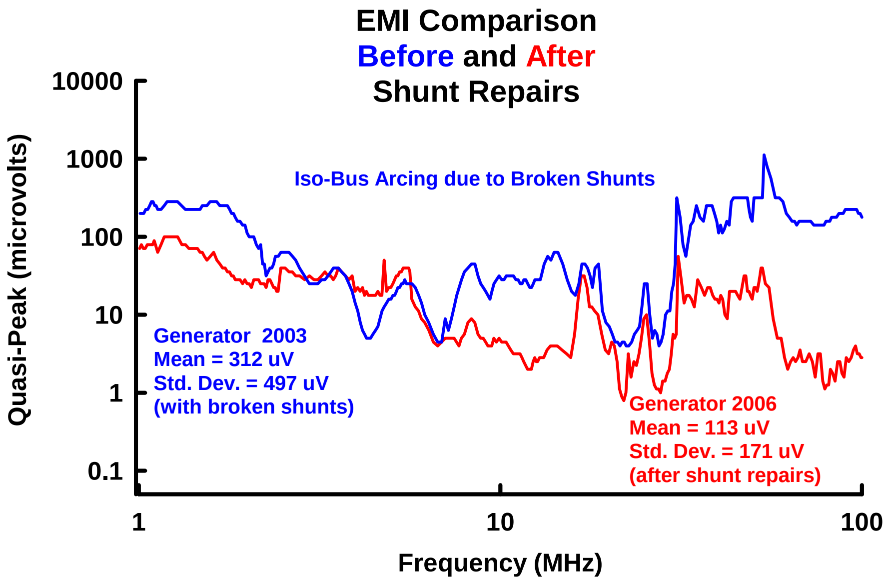

FIGURE 17: With broken conductor shunts repaired the high frequency EMI signature returned to earlier levels, confirming these repairs successfully corrected the problem.

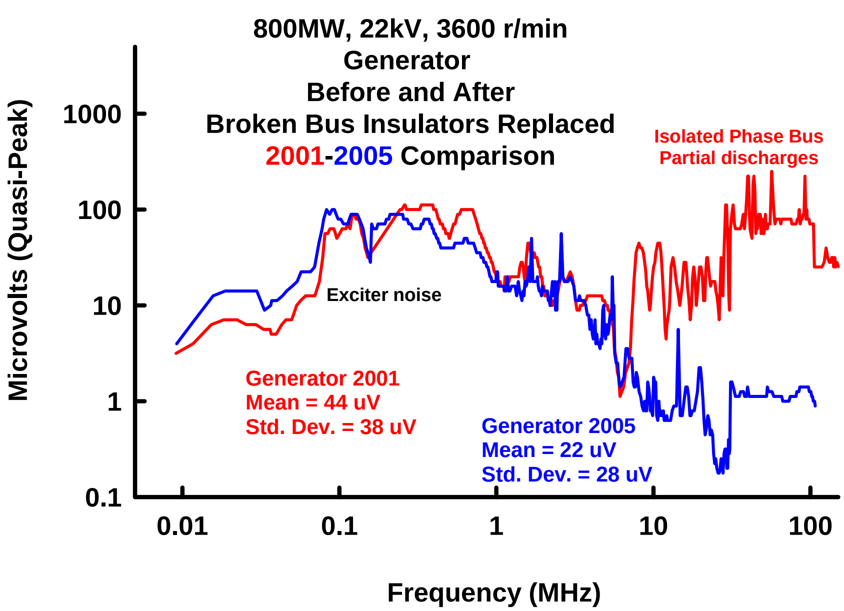

FIGURE 18: The 2001 EMI signature for this generator indicated severe bus deterioration.

An EMI Diagnostic of this generator system discovered high levels of bus related partial discharges. This bus is subject to high vibration levels due to a floor resonance condition. The 2003 inspection located six separated support insulators, Figure 19. After insulator replacement the EMI signature returned to "normal". The floor was de-tuned from 120 Hz.

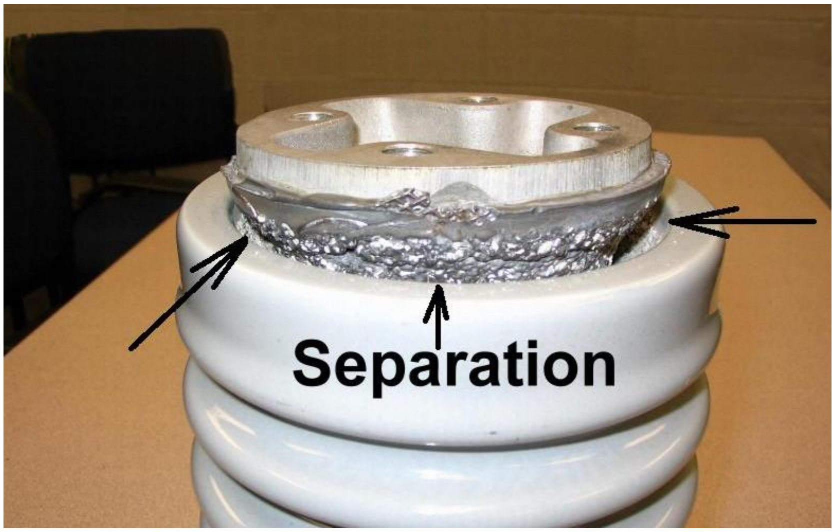

FIGURE 19: A bus inspection of the system in Figure 18 found six insulators with loose mounting inserts.

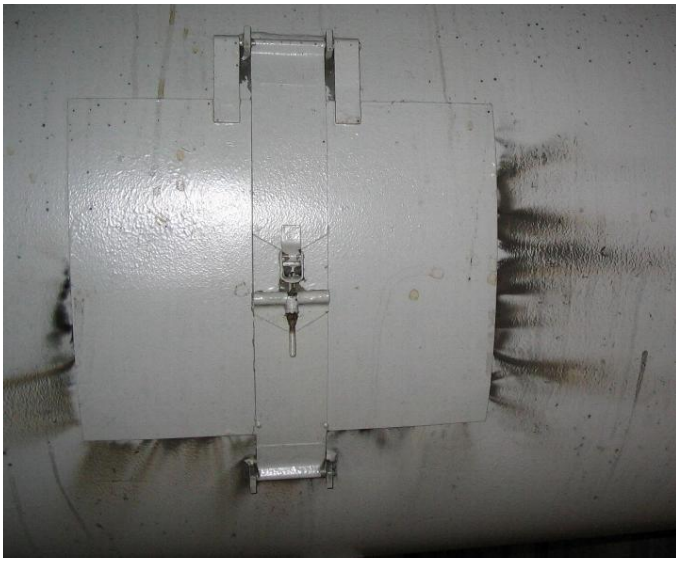

FIGURE 20:Forced air-cooled isolated phase buses often develop air leaks around the inspection hatches due to hardening of the original gasket material.

Deterioration of the rubber gaskets around bus inspection hatches can be expected. The original material was not intended to remain pliable for longer than 10-15 years. In some cases the seal was compromised within 5 years due to higher than expected operating temperatures. Materials available today such as silicone rubber sponge can be applied as a permanent replacement gasket. This 180^0 C temperature rating material has proven to remain an effective air seal after 20 years of operation. Similar deterioration of the enclosure air seal near the GSU Figure 21 is also common. Replacement with silicone based material is recommended.

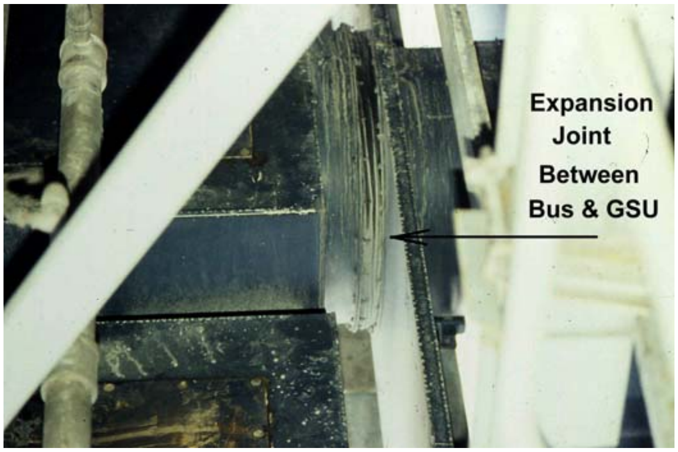

FIGURE 21: Deterioration of the air seal between bus and GSU can be expected.

FIGURE 22: The neutral enclosure under a generator is a section of bus often over looked.

The neutral bus in Figure 22 carries 30,000 amps with out forced cooling. Enclosure circulating currents and operating temperatures were sufficient to deteriorate the surface paint. An infrared inspection would have clearly shown this problem. Since many systems are being upgraded with more efficient turbines the resulting higher operating temperatures may result in more than chalked paint. Additional ventilation holes were added to the enclosure in Figure 22 to improve convection cooling.

Insulation Replacement

The original bus insulation materials consisted of fiber, plastic, rubber and cork that usually lasted 10-20 years. Improper selection of materials along with higher than expected operating temperatures have resulted in insulation failure much sooner at some locations. Modern replacements of high temperature rated insulation and gaskets can be a permanent fix with 30+ years of expected service. All of these suggested isolated phase bus repair materials have been found to remain in excellent condition after 20+ years of service.

Non-continuous enclosure insulation materials continue to improve. High temperature papers (such as Nomex ™) are readily available. Silicone RTV rubber has proven to be an excellent high temperature adhesive to hold insulation on enclosures. Silicone rubber foam makes a thick resilient air and moisture tight gasket that can serve for several decades. In all cases the materials and aluminum must be totally free of oil and dirt before the adhesive is applied. All original gasket material must be removed and the area cleaned with denatured alcohol just before the RTV is applied. Clean dry paper towels are preferred over the use of rags to clean the surfaces. In some designs only one end of the enclosure is insulated, this prevents testing the insulation. One solution has been to insulate both ends of the enclosure. Isolation can then be verified with an insulation resistance test. The normal ground strap at one end will provided the necessary single point enclosure grounding. If problems are suspected, this external ground can be lifted and the enclosure insulation tested.

SUMMARY

Isolated phase bus should be inspected annually with IR and EMI as well as visually. Deterioration of some components can be expected. Replacement materials can be installed that will to provide service for remaining life of the plant.

REFERENCE

Robert H. Rehder, Louis Doucet, Maintenance Considerations on Isolated Phase Bus Duct, Doble Spring Meeting 1995, paper 62PAIC95.

James E. Timperley (BSEE, 1968 Oklahoma State University) joined American Electric Power in the station engineering department. He is currently a staff engineer at the corporate office in Columbus Ohio. Jim has published over 65 technical papers on operating, maintaining, testing and repairing rotating electrical machinery. Other activities include maintaining high current isolated phase bus, equipment root cause failure analysis, the development and application of EMI Diagnostics as well as R&D projects dealing with advanced insulation materials. Mr. Timperley is an IEEE Fellow and was presented the 2006 Dakin Award by the IEEE Dielectric & Insulation Society for the development of EMI Diagnostics. He is a past chairman of the Doble Rotating Machinery Committee, active in several standards groups and a registered professional engineer in the state of Ohio.