Isolated Phase Bus Duct Systems –
Inspection and Maintenance Best Practices

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ABSTRACT

The purpose of this presentation is to educate the audience on best practices that have been identified for analysis, inspection, cleaning and maintenance of power plant bus duct systems. Many plant managers ignore bus duct, forgetting it is the only system critical component in the power plant that does not have redundancy.

The presentation will provide first-hand insight into forty years of experience and field findings of the Nation’s premier high voltage power conductor experts. Presentation topics will include case studies detailing inspection options (both online and offline), the ramifications of poorly and/or inadequately maintained bus duct systems, current trends in predictive maintenance programs, and best practices for bus duct inspection and cleaning (including insight into the newest technologies available).

Agenda

• Introduction
• Isolated Phase Bus (IPB) Basics
  o Types of IPB
  o Manufacturer’s Maintenance Recommendations
  o IEEE STD. C37.23-2003
• What Causes Isolated Phase Bus Failures
• IPB Inspection & Maintenance Scope Of Work

INTRODUCTION

According to the 2014 Electric Power Annual on eia.gov, the U.S. Energy Information Administration, electricity consumption is expected to increase nearly 30 percent by 2040. Your bus duct system is the only system critical component in your plant that has no redundancy and no ‘quick’ fix if it fails. With recent closures and proposed closures to both coal and nuclear units; is your plant prepared to handle the demand increase?

ISOLATED PHASE BUS BASICS

The presentation will begin discussing bus manufactures & maintenance recommendations, the main components and purposes of the Isophase, as well as the IEEE standard C37.23-2003. It is important to understand the purpose of bus duct in order to realize the critical job it plays
within the system and the importance of properly inspecting and maintaining it on a regular basis.

**Main Components & Purposes**
The Isolated phase bus (IPB) systems transfer the current from the Generator to the Generator Step-Up Transformer (GSU). This portion is considered the Main Bus. Auxiliary Bus is used to tap off of the Main Bus to feed current to auxiliary equipment including: Auxiliary Transformers, Exciter Transformers, P.T. or Surge Cubicals, and a variety of other possible pieces of equipment. Compartments are used at the Generator, GSU, and other pieces of equipment to house the conductor terminations, and to complete the connection of the bus enclosure to the equipment. In some cases, cooling units are utilized to blow chilled dry air through enclosures to cool conductors on some higher current IPB systems. Dissipation of heat in this manner allows a higher continuous current rating of the bus. IPB with this equipment operates under the “forced cooled rating”, compared to the “self-cooled” rating without this equipment. These cooling units are not considered separate pieces of equipment, but are an integral part of the IPB system. Also, in most cases the P.T and Surge Cubicles are considered part of the IPB system, if they are built along the isolated phase concept. There are a variety of different types of bus that can be used within a power plant for different purposes including Isolated Phase Bus (IPB), Segregated Phase Bus (Seg), Non-Segregated Phase Bus (Non-Seg), and Cable Bus, but IPB is normally used as the generator or main bus.

**Types of Isolated Phase Bus**
Isolated Phase Bus (IPB) can be divided into two major design types, continuous or non-continuous.

The design of Non-Continuous IPB utilizes either one of the outside phase enclosures (GE design) or a continuous ground bar running along the support steel (ITE design), as the system ground. The longitudinal bus enclosures are then isolated from the next section and grounded across to the outside enclosure (GE design) or the ground bar (ITE design). Cooper shorting rings around the supporting steel under each enclosure which help cancel induced currents are a positive indication the bus system is non-continuous.

A continuous IPB system utilizes all welded construction of the bus enclosures to provide a continuous path for the ground currents. The enclosure current is nearly equal to the conductor current, but in the opposite direction. The magnetic field surrounding the enclosure is minimal, and therefore induced heating in support structures around the bus is very small. The enclosures are bonded to each other at all bus termination ends with shorting plates. By design, the shorting plates between the phases utilize the same minimum cross sectional area as the enclosures. This causes the induced ground currents to theoretically cancel each other out. The IPB system is then grounded at one point only, usually the GSU transformer, which eliminates the chance of forming circulating ground loops. Although the different IPB manufacturers have different aspects to their design, the basic continuous IPB design is now the industry standard.

**Manufacturer’s Recommended Maintenance Schedule**
Each bus duct manufacturer has a system specific recommended maintenance schedule. AZZ Calvert recommends that your system be checked every scheduled outage or a minimum of
every 18 months. GE proposes maintenance of your system during the first year of operation,
whenever the generator is shut down, and at least once a year after that. Powell and
ITE/SpecFab require yearly maintenance, with SpecFab adding maintenance at every
scheduled outage as well. Technibus/ABB recommends maintenance to be performed at every
major outage, while Westinghouse recommends every scheduled shut-down or a minimum of
every 18 months.

**Governing Standards**
Isolated Phase Bus, Segregated Phase, and Non-Seg Bus are all governed by IEEE Std.
C37.23 - 2003 IEEE Standard for Metal Enclosed Bus. This specification covers all aspects of
the components of these bus systems including the design requirements, service conditions,
ratings, testing requirements, construction requirements, accessories, and special requirements
in unusual service conditions. It also covers cooling units (if required), and Surge and PT
cubicles which are built per the “isolated phase” concept.

NOTE: This standard covers the “entire” bus system, and in turn the “entire” bus system should
be governed by the Generating Plant. Some company’s policy is that the GSU transformer
“belongs” to the “Transmission & Distribution” group instead of the generating plant. They also
require that the T&D group is responsible for any work done on that transformer, including the
bus terminations. Disconnecting and reconnection of the IPB termination to this equipment once
or twice a year should not be considered as being properly qualified to actually perform this
task. Upon discovery, it has been found that this practice has led to major damage to the bus
components, and can create situations that could lead to loss of the transformer itself. These
bus systems are specialized pieces of equipment that require specialized training for
technicians working on them.

**WHAT CAUSES ISOLATED PHASE BUS FAILURES**

IPB failures can be broken down into three major categories: Other Equipment, Weak Points in
a Manufacturer’s Basic Bus Design, and Improper Inspection & Maintenance.

**Other Equipment**
In many cases, damage to the IPB system can be attributed to a failure in another piece of
equipment. At the same time, those failures may possibly have a root cause in the IPB system.
Did the failure occur because of something happening with the equipment, or did something
happening with the bus cause the failure to occur at the equipment termination. In many cases it
is almost impossible to determine the root cause of these types of failures. This is why it is
valuable to perform EMI diagnostic assessment regularly while your system is online so you can
establish a baseline and stay aware of potential trouble area before they fault.

**Bus Design**
Each bus manufacturer builds a Non-Continuous style of Isolated Phase Bus, but the basic bus
designs from each manufacturer have many differences. They also seem to omit components
needed to properly perform maintenance on the bus. Many bus designs don’t provide access
points to ensure proper cleaning of internal components such as insulators, seals, and
laminated conductor flexes. Failures of these components are common. One design uses
cables to make enclosure expansion joints continuous. The cable with the best connection
carries the most current so it will fail first, then the next best cable. This turns into a cascading
effect. There is also a design that suspends the conductor under the insulator. An insulator is
best used in compression, not tension. After years of usage, the vibration in the IPB system
weakens the ceramic insert in the insulator and it will fall apart, allowing the conductor to fall down to the bottom of the enclosure.

**Improper Installation & Maintenance**

The most commonly found issue with bus duct systems is improper installation and maintenance, and in some cases virtually no maintenance. There have been many instances where the plant can’t remember the last time the bus had been opened up and inspected, or if it ever has. The only thing known is the paint is peeling off the enclosure because of the excessive heating, or they can’t get it to pass the HiPot test, or it blew up. These same “type” of problems can be evidence of improper installation. The bus may function under these types of conditions for years or only days. It all depends on the severity of the condition, and the amount of secondary damage being done. The importance of having a qualified contractor, experienced in the installation of bus systems WITH proven project continuity, cannot be understated. Insurance companies are taking notice. Plants that cannot provide documentation showing adherence to the manufacturer’s maintenance recommendations are starting to see rates go up. This brings us to the largest cause of damage to bus systems; the use of improper maintenance procedures and inexperienced maintenance personnel have been found to cause actual damage to the bus components in a vast majority of the bus systems. This can vary from the use of improper hardware components, improper torquing of bolted assemblies, to not realizing that something is actually a cause or symptom of a problem when they are looking at it. Experience and Knowledge is the key to overcoming this issue. “Just because it was working fine “as-is” for a long time, doesn’t mean that it won’t blow up the next time it’s energized”. If something is wrong, it needs to be fixed, ASAP.

**IPB INSPECTION AND MAINTENANCE SCOPE OF WORK**

**Research, Planning, & Documentation Procedures**

The best advice on this subject is, “PLAN YOUR WORK” (ahead of time). When a new IPB system is installed Weld Maps are required to show who welded each joint on the conductor and enclosure. Plans should be made to treat each specific point of inspection the same way. Document everything, including things that are correct.

To plan for this, all the drawings, bill of materials, pictures, and other information including history of previous inspections concerning the bus system should be obtained. Review of all information can then be performed to determine the specific scope of work. Then determine what standard replacement parts and materials will be required for procurement before the outage, what equipment and/or scaffolding will be required, and what special parts or materials may be required upon discovery. In addition, have a contingency plan ready in case special parts, materials, and labor are required upon discovery.

Then, set up a systemic listing of each inspection location, with tasks required, and specific observation and inspection hold points. All documentation including pre & post maintenance pictures should reference the specific inspection location. A master set of installation drawings, or sketch of the bus system showing specific inspection locations should be kept and updated as needed. Forms for documentation of satisfactory completion of all required tasks and inspection hold points per location should be kept.

Also, set up a procedure for documentation of as-found damage and other items of concern. Any component damage or other concerts should be documented and submitted immediately to the plant for decision on corrective action.

**EMI Diagnostic Testing (recommended)**
It helps to have an idea of the severity and general location of many of the problems before you start the actual work. Electromagnetic Interference (EMI) Diagnostics should be performed, before the outage, while the bus is energized. This is an on-line, non-invasive test that can detect a wide variety of IPB defects. EMI testing offers many benefits including, a broader view of system defects including partial discharge and corona. It also empowers improved condition assessment and can optimize preventative maintenance programs. The bottom line is EMI Diagnostics testing is a valuable tool which can be used to assess system condition prior to the planned outage. This will further aid in planning and scheduling the Inspection & Maintenance activities during the outage.

**Basic Walk-Down Observations**
This can be done before, or at the beginning of the outage. Look for evidence of misalignment of bus sections or equipment, which is normally caused by incorrect installation of the bus or equipment, or by setting of support structures. You will also need to look for peeling of paint or discoloration of the bus enclosure or compartments. This is evidence of possible excessive heating. Also, inspect the support structures for evidence of rusted or burned bolting hardware. This shows there are possible grounding problems or excessive induced currents in the support steel. When the ground current uses a bolted assembly as the ground path, it will eventually corrode the assembly causing the ground path to change to another assembly of lower resistance.

**Lock-Out Tag-Out Procedure**
Before any inspection of the IPB, verify the bus is de-energized, grounds are in place, and all involved personnel are signed on to the plant’s Lock-Out Tag-Out procedure for the involved system. Safety should always be considered “Priority One”.

**Inspection of the Equipment Terminations & Components**
1. Visually inspect the as-found termination assembly to verify the design per the IPB installation drawings. Pictures should be taken from several angles for documentation and discrepancies or apparent modifications should be documented and reported.
2. As-found torque value of each bolt assembly should be taken and recorded. Lower than normal torque values are evidence of loose joint and can cause excessive heating. Low torque values are caused by improper installation, thermal cycling, or improper hardware, higher than normal torque values indicate improper installation.
3. Termination components should be completely disassembled, labeled, and organized, including the hardware. Components of each phase should be kept separate.
4. Inspect and verify that the Termination Compartment is properly isolated or grounded per design. The hardware, gasketing, and any other components used in connecting the compartment to the equipment should be inspected to ensure correct components are being used, and to ensure they are not damaged. Corrosion on the hardware or burn marks on the isolation components is evidence of incorrect grounding.
5. Inspect inside the compartment and the end of the IPB for evidence of condensation and water intrusion.
6. Inspect the conductor component contact surfaces for warping or discoloration (this is evidence of excessive heating), and for scaring and flatness. Check the bolt holes for deformities (improper hardware installation).
7. Inspect the silver plating on all contact surfaces, including the flexes.
   NOTE: Per IEEE C37.23, the maximum temperature limit for bolted conductor connections that are plated is 105°C. Unplated bolted connections have a maximum temperature limit of 70°C. The bus is designed to operate at the 105°C limit, so unplated joints will create excessive heat, which in turn will damage the components.
Pre-Maintenance HiPot Test
Each phase of IPB should be subjected to a Power Frequency Withstand test (Hi-Pot) after all equipment terminations are disassembled and before other inspections and maintenance is performed. Leakage current for each phase should be documented and used as a baseline for testing after the completion of inspection and maintenance. Testing at this time will pinpoint potential problem areas such as hairline cracks in insulators that visual inspection might normally overlook. The BIL level of the IPB system will determine the test value.

Main & Auxiliary Bus Inspection
The interior of the IPB enclosure should be inspected for foreign objects, water intrusion, corrosion, and other contaminants such as direct, coal dust, and carbon deposits produced from smoke migrating through the enclosure during previous fault. A large amount of corrosion inside the bus enclosure is normally evidence of a combination of water intrusion and cathodic action caused by excessive ground currents flowing through the enclosure. If contamination, such as this, is sufficient, cryogenic cleaning of the bus is recommended. As mentioned before, additional access ports may be required to facilitate this cleaning.

If a strict inspection and maintenance schedule has been used for the bus system, only a sampling (20%) of the insulators need to be inspection and cleaned. Documentation is required to insure different groups of insulators are being checked during each inspection. If contamination is found on any of the insulators checked, all insulators must be inspected and cleaned. If a regular inspection and maintenance schedule is not adhered to, all insulators must be inspection and cleaned. Some bus manufacturers do not provide adequate access points to perform the inspection and maintenance of the insulators. If this is the case Access Ports must be installed in the bus enclosure to allow inspection. Internal video inspection via the use of a robotic crawler camera is also an option.

NOTE: The following are specific common areas of Inspection & Maintenance which must be performed as required. Not all bus systems are alike. Some of these will apply while others will not.

Complete Cryogenic Cleaning of the Bus
Grounding Verification & Inspection
Inspection of Seal-Off Bushings (both sides)
Inspection of Bolted Disconnect Joints
Inspection of Welded Enclosure Expansion Joints
Inspection of Enclosure Expansion & Term’s Bellows
Inspection & Testing of the Condensation Control System
Inspection of the P.T. & Surge Protection Equipment

Post Maintenance HiPot Test
Upon completion of the Inspection & Maintenance, the bus should be subjected to another HiPot test comparable to the initial test. Results should be compared to determine the success of the project.

**Documentation Review and Reporting**
All documentation should be reviewed and submitted along with final reports to the plant.

**CONCLUSION**
In conclusion, the experience of the company and its employees performing the inspection cannot be emphasized enough. Inexperience could lead to equipment damage, unscheduled outages, and possible personnel injury. A bus duct contractor should have extensive technical knowledge of all applicable IEEE standards, types of bus, and specific designs variances of all bus manufacturers. They should also have vast installation experience on all types of power plants; including nuclear, coal, gas, and hydro. There should be standard procedures, protocols, and documentation covering all aspects of the inspection. This documented information is vital during the planning, inspection, repair, and review phases of the work. Lastly, all employees should be properly trained in all aspects of the items mentioned above. This should be formal training specific to this purpose. Without this training, many abnormalities may not be identified during the inspection.

**BIOGRAPHY**

*Gary Whitehead has been the Power Projects Specialist at Electrical Builders, Inc. (EBI) for the past four years. Since coming to EBI, his main focus has been working on projects involving new installations and retrofits as well as design improvements and value engineering on existing systems. Mr. Whitehead has earned an Associate’s Degree in Drafting and Design Technology, as well as additional studies in Industrial Technology. He has taught for three years, and has over twenty-five years of experience in varying fields, including Architectural, Mechanical, Industrial, Civil, and Electrical Engineering. He has more than eleven years of experience in the power industry before joining EBI, working for AZZ/Calvert, a manufacturer of Isolated Phase Bus, Non-Seg, Segregated Phase Bus, and Cable Bus systems. With AZZ/Calvert he worked in their engineering department as a Designer, Checker, and Engineering Technical Coordinator, and also in their Installation Services Department as a Designer/Quotation Specialist and Project Manager.*

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