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GUIDANCE FOR CONDUCTOR JOINTING IN SUBSTATIONS

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PURPOSE AND SCOPE

Within a substation there are many electrical connections ranging from high current busbar and earthing joints down to small assemblies on electronic circuit boards. This appendix deals with the former i.e. connections required to carry either primary load current or fault current or both. The associated maximum permitted temperatures under these conditions in accordance with NGTS 3.1.2 are 90°C and 405°C (325°C for aluminium). This appendix does not cover equipment contacts, contractors, and sliding/moving contacts for which specific and detailed installation and maintenance instructions exist.

The integrity of busbar and earthing connections is essential for the security and safety of the high voltage substation. They are heavily loaded and temperatures at the connection interface are high such that degradation of poorly made and maintained joints is likely. Outdoor connections that operate under all weather conditions require protection to avoid corrosion induced long-term degradation.

The aim of this document is to provide guidance on good practice for conductor jointing in substations and it is Informative rather than Normative in nature. It aims to promote a good understanding of how to achieve high quality electrical connection and details typical problems encountered within the jointing process. Particular emphasis is placed on bolted joints for two reasons. Firstly, they can be less secure than joints which rely on fusion of materials e.g. welding and secondly, many bolted joints are disconnected for maintenance or to provide electrical isolation and thereby are at risk of being incorrectly remade.

PART 1 – GUIDANCE

1 JOINTING GUIDELINES

There are a wide range of jointing methods available but, without exception, their effectiveness relies on trained people working to established procedures. Inadequately trained workers or a disregard of the precise instructions is liable to be unsafe and result in an inadequate connection.

Appendix A & B provide a summary of different joint types, their application suitability and appropriate standards that may apply. Where particular jointing instructions exist, they should be followed, since they will normally have been developed and tested by the manufacturer or supplier.

2 BOLTED JOINTS

2.1 Preparation of Unplated/Untinned Bare Surfaces of Bolted Joints

Brushing using a stainless steel wire brush is widely used to remove gross oxide films and contamination and to create the rough sharp peaks needed for good electrical contact. However, the ends of the steel tines become rounded after repeated use and the brush then loses its effectiveness. A more reliable method of abrasion is to use aluminium oxide cloth grade 80. Aluminium surfaces require particularly diligent surface preparation.

The following procedure has been found to give consistent low resistance joints.

- a) Use a suitable solvent to clean dirty or greasy surfaces such as Elecsol 41 or Elecsol Super which may be obtained from Forward Chemicals Ltd, Tel 0151 4249441
- b) Remove any burrs around bolt-holes or edges. Busbar or strip should be flat and any noticeable bowing or distortion should be removed.
- c) Use a fresh strip of aluminium oxide cloth Grade 80 and thoroughly abrade the mating surfaces.
- d) Without delay, coat each surface with a thin layer of suitable grease for jointing, e.g. Castrol 'Rustilo 431' or equivalent.

Certain types of joint combinations can develop instability if operating at continuous high temperature. For these types of joint, a suitable transition interface should be used as indicated in Appendix A. One of the methods of achieving this is by transition washers, which can be obtained from Sicame Electrical Developments Ltd, Huddersfield, Tel 01484 681115. The assembly instructions provided should be strictly followed.

2.2 Preparation of Tinned or Plated Surfaces of Bolted Joints

- a) Use a suitable solvent to clean dirty or greasy surfaces such as Elecsol 41 or Elecsol Super, obtained from Forward Chemicals Ltd Tel 0151 4249441
- b) Remove any burrs around bolt-holes or edges. Busbar or strip should be flat and any noticeable bowing or distortion should be removed.
- c) Do not prepare plated surfaces unless they appear badly tarnished. A toothbrush/nylon nailbrush or similar can be used to remove tarnish without scratching the plating. The exception is nickel plating which has a surface film which can inhibit good contact if the contact pressure is low. It is prudent to abrade this surface lightly and carefully with grade 400 oxide paper.
- d) Without delay, coat each surface with a thin layer of approved grease for jointing, e.g. Castrol 'Rustilo 431' or equivalent.

Note The surfaces of bolted joints that are working in transformer oil should be coated with Petroleum Jelly. Other greases may be chemically incompatible.

2.3 Assembly of Bolted Joints

- a) Ensure that nuts run freely on the bolts or studs.

- b) Assemble the joint as soon as possible after the surfaces have been prepared to minimise oxide growth and contamination of the surfaces.
- c) Ensure the correct sized washers have been placed under the bolt head and nut before tightening.
- d) Tighten using a torque wrench set for the size and grade of bolt material.
- e) If the electrical connections allow, measure the resistance of the joint and check the value is less than the resistance of the same length of un-jointed bar.
- f) Protect joints used outdoors against corrosion. Smear a liberal amount of grease e.g. Castrol 'Rustilo 431' or equivalent around the joint edges of similar metal joints. If the metals are dissimilar e.g. aluminium bolted to copper, overwrap the whole area of overlap with anticorrosion tape such as Densochrome Tape or preinstall a heat shrink sleeve packed with Castrol 'Rustilo 431' grease or equivalent. Mastic may be more practicable for complex shapes.

Note Do not install copper to aluminium connections with the copper above the aluminium as copper salts can drain down and cause electrolytic action.

2.4 Service Performance of Bolted Joints

Bolted joints prepared and assembled in accordance with the above recommendations should give a long and trouble-free life making continuous monitoring unnecessary. However, joints which carry high continuous or cyclic currents or which experience mechanical disturbance, vibration or shock may be susceptible to some degradation and a consequent increase in electrical resistance. Overheating may result.

Measurement of joint temperatures using an infrared camera or measurement of joint resistance can be used to ascertain the condition of current carrying joints. A joint resistance greater than the resistance of the same length of unjointed conductor is a cause for further investigation and, if possible, a comparison should be made with the resistance of similar joints and with commissioned resistance values.

3 OTHER METHODS OF JOINTING

This section briefly describes jointing techniques, other than bolting, with an indication of their effectiveness, security and problems.

3.1 Gas Shielded Electric Arc Welding (MIG – TIG)

Welding of copper, aluminium and steel produces efficient and compact joints and is useful for jointing tubular conductors and conductors of different cross-sections. Effective jointing relies on correct procedures being followed (see BS 3571-1 and BS 3019-1) and appropriate training (see BS 4872-2 and BS EN 287-2). Particular attention must be paid to the effective tenting of the work area to ensure a relatively draught free environment. Failure to maintain this environment can result in the gas shield being broken resulting in porous or oxidised welds. Measurement of the resistance of completed joints is unnecessary since the electrical contact area is relatively large. Sample testing of completed joints should be undertaken in accordance with BS 3451 and BS EN 1320.

3.2 Fusion Electric Arc Welding, Gas Brazing and High Temperature Soldering

These techniques are a common and convenient way of joining copper, aluminium and certain other materials. During fillet or lap jointing of aluminium the fluoride flux used during the jointing process is liable to entrapment between contracting metal surfaces. This material is inherently corrosive and may cause joint deterioration over time despite initial indications of an effective joint. On this basis this technique should be avoided.

Electric arc fusion welding of copper is unsatisfactory due to porosity and brittle inter-metallic formations impairing the mechanical properties of the joint.

Copper/aluminium jointing requires careful control and the provision of a 0.75-1mm layer of silver brazing alloy to the weld area of the copper. This is metallurgically compatible with both copper and aluminium and jointing can be performed by direct fusion welding using conventional aluminium-silicon filler metal.

Jointing of copper to rebar steel or wrought iron can be achieved by 'bronze welding'. This reference to welding is misleading since there is no melting of the parent metals. A strong bond is created by the flow of the filler metal and the wetting of the parent metals. The filler wire consists of copper rich alloys and has a lower melting point than the parent metals. Joint preparation and cleanliness are essential to ensure that the molten filler metal flows over the complete joint area. Joint quality is not easy to determine since the electrical resistance will normally be very low. BS EN 1320 recommends the use of a fracture test conducted with dynamic sensible strokes (3 off) applied from a hammer to check whether the joint is sound.

3.3 Explosive Jointing / Cold Pressure Welding

These techniques are used mainly for joining aluminium-aluminium and copper-copper. The technique bonds material mating faces by compression from either explosive detonation (explosive jointing) or the hydraulic application of localised compressive forces (cold pressure welding). Cold pressure welding typically employs interconnection by four weld dimples. Joints of this type are particularly difficult to maintain since the resistance of the individual dimples must be measured to ensure the joint integrity.

Experience has shown that aluminium/copper joints of this type suffer from the formation of brittle inter-metallic compounds during the jointing process. Aluminium/aluminium joints suffer similarly if joint face preparation is inadequate. Joints of this type have been known to fail as a result of a hammer blow and, in extreme cases, with no apparent external interference. These methods of jointing are considered unacceptable to National Grid Transco (NGT).

3.4 Eutectic Welding

This technique employs a carbon crucible and an ignitable eutectic mixture surrounding the area to be joined. Localised heating causes fusion of metal to eutectic. Specialist companies market the components for eutectic welding and the precise jointing instructions must be followed if a successful joint is to be made. Copper – copper, copper – aluminium and copper – steel combinations are possible. Joints involving steel require particular care in their preparation. The eutectic that is formed may have a melting point lower than that of the parent metal. Earthing strip joints, for example, which may rise to very high temperatures during high intensity faults are particularly dependent on the eutectic properties. The supplier must always be consulted in case of doubt.

A mechanical shock is the only way to check the joint has been satisfactorily fused. The finished joint often appears with small blow holes which do not detract from joint efficiency but the porosity could contribute to corrosive degradation in the longer term. A coating of bitumastic paint will provide protection.

3.5 Compression Jointing

This method is applicable to joining solid or circular conductors. It is important that the dies, compression tools and the ferrules or lugs from the same manufacturer. Subject to this requirement, the main features are cleaning of the conductor, the correct use of the die (that is the number and order of compression bites) and applying the correct pressure from the hand or hydraulic tool. Greasing of the conductor may be specified to enhance stability and inhibit corrosion.

Compression jointing of flexible aluminium conductor in a substation requires diligent attention to surface preparation. Manufacturers were faced with considerable difficulties in the 1970's in designing compression jointing systems for aluminium conductors that were stable over a thirty year lifespan and many changes to design parameters have been made. Surface preparation and adherence to jointing instructions is equally important today and a measurement of the electrical resistance after assembly is vital. The resistance of the joint should be less than the resistance of the same length of conductor however more specific pass/fail figures are often provided by the supplier.

Greasing of outdoor compression joints is especially important. The large compression joints used on down-droppers from an overhead line entry are particularly susceptible to inadequate greasing of the barrel since water can drain down into the joint and set up a corrosive cell.

4 SURFACES IN CONTACT

4.1 Background Information

Metal parts welded together by thermal fusion or brazing are kept in intimate contact by molecular attraction forces that are a characteristic of all solid materials. They act as one material with electricity able to flow without hindrance across the interface. In practice there may be occlusions and voids which reduce the mechanical strength of the joint. They also reduce the area for conducting electricity but there is normally so much redundancy in electrical contact area that overheating is not a problem.

Metal parts welded together by the action of pressure alone are also held in intimate contact by molecular attraction forces. However, pressure welded joints have significantly less area in mechanical and electrical contact than heat fused joints. Surface oxide films are only ruptured and they remain within the interface as non-conducting areas which have little or no mechanical bonding strength. Recent experience within NGT is of pressure welds failing during normal service and also after site checks were conducted by tapping the joints with a 'sensible blow' from a hammer. Principally these failures have been attributed to unsatisfactory surface preparation prior to the jointing process. Since this preparation is difficult to guarantee this method of jointing is presently unacceptable to NGT.

Finally there are purely mechanical joints of bolted or compression type. Bolted joints are characterised by the drilling of the mating surfaces and clamping by means of bolts. These joints are readily disconnectable and are commonly used. Compression joints involve the sliding of a ferrule or tubular lug over a circular or shaped conductor. The two parts are then forced into intimate contact using a mechanical tool with indenting dies. The hoop stress created in the distorted ferrule maintains contact. This connection is commonly used for cable & flexible conductor ends and once made can only be removed by cutting off the complete assembly.

4.2 Basic Principles

An understanding of the fundamentals of surfaces in contact is important if bolted joints are to be correctly made and maintained.

When two surfaces come together under pressure contact is made where the highest peaks or asperities meet. Even surfaces apparently smooth to the eye are sufficiently rough on a microscopic scale for the contact to be limited to isolated points. These points are under such high pressure that they deform plastically until sufficient contact area exists to support the applied mechanical load. Current flowing across the interface is thus constricted to the small areas in contact – see Figure 1.