PECULIARITIES OF ELECTRICAL DESIGN IN GEOTHERMAL POWER PLANTS

Eric Wolters

Technical Director, Power; Parsons Brinckerhoff, Level 9, 21 Queen St, Auckland 1140, New Zealand

Wolterse@pbworld.com

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ABSTRACT

Most engineers in the power industry are aware that one of the by-products in geothermal energy exploitation is hydrogen-sulfide gas (H_2S). Besides smelling bad and causing rapid corrosion of iron and steel, H_2S reacts with various materials commonly utilised in electrical and control systems installation including copper, silver, nickel-silver, cadmium, brass, bronze and phosphor-bronze. Therefore design of electrical systems in geothermal environments must stipulate extraordinary measures to protect electrical components from corrosion during the life of the plant.

These protection measures are not confined to material selection. The presence of H_2S in the atmosphere gives rise to a number of building, building services, control system and electrical reticulation system design considerations that are peculiar to geothermal power plants.

This paper describes the common problems and commonly-applied engineering solutions, and also describes one of the electrical design innovations that the team at Parsons Brinckerhoff has introduced on a recent geothermal project.

1. GENERAL

Hydrogen sulfide (sulphide) is the chemical compound with the formula H_2S. It is a colourless gas with the characteristic foul odour of rotten eggs. It is heavier than air, very poisonous, corrosive, flammable and explosive when mixed with air. H_2S reacts with many metals to form metal sulfides. H_2S is present in all geothermally active areas, and in geothermal power plants is present in especially high concentrations around the cooling towers, non-condensible gas extraction plants, and any place where steam or non-condensable gases are discharged to atmosphere. Such places include vents and steam drains, well pads and rock mufflers. See Figure 1 for examples of H_2S corrosion at geothermal power plants.

Extraordinary measures are specified in geothermal power plant design to protect the metals most susceptible to reaction with the H_2S gas. Typically carbon steel is protected through hot-dip galvanising or two-pot epoxy paint systems. Hermetically sealed 316 stainless steel or Fibre Reinforced Plastic (FRP) IP66 or NEMA 4 junction boxes and SS fasteners are specified for all areas that have high concentrations of the gas; and the use of aluminium (which is immune to H_2S corrosion), fibreglass, FRP and PVC is encouraged for ancillary equipment such as cable ladder systems and conduit. Air conditioning systems feature large amounts of copper in piping and heat exchangers, and must be specially designed for a geothermal environment.

Copper is by far the most useful metal in the electrical design toolbox, but copper and all of its alloys rapidly corrode in air with even small concentrations of H_2S. Silver is also highly susceptible.

Where the use of such materials cannot be avoided then other measures to prevent exposure to atmosphere must be applied, or filtering of atmospheric air undertaken to eliminate H_2S.

It should be noted that the same issues apply to some hydro plants where decomposition of foliage in newly filled reservoirs results in release of H_2S gas.

Section 2 describes each of the design measures that are currently applied to geothermal power plants to prevent electrical system failure due to H_2S corrosion.

Section 3 describes one of the innovations introduced at a recent power plant project undertaken by Parsons Brinckerhoff.

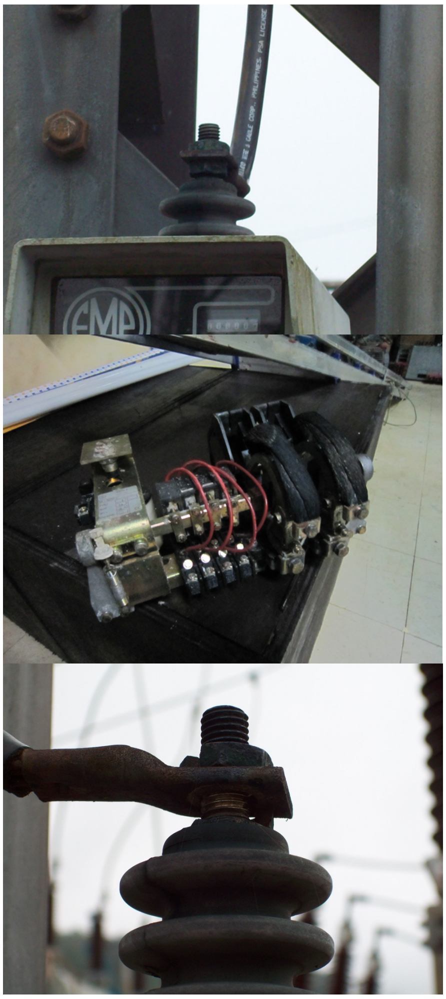

Figure 1: Examples of H_2S corrosion at geothermal power plants.

2. COMMONLY APPLIED MEASURES TO PREVENT H_2S CORROSION IN ELECTRICAL SYSTEMS

2.1 Material selection

2.1.1 Current carrying conductors

Although aluminium is a viable alternative for copper in many current carrying applications, it has the disadvantage of needing significantly larger physical dimensions to carry the same current, and thus needing more physical space, both in cable runs and at terminations. It is also less ductile than copper and therefore it is more difficult to manipulate, requiring larger bending radii than equivalent copper cables.

While aluminium does not corrode, it does oxidise and this can lead to increased joint resistance, which can in turn lead to overheating. The maintenance requirements for aluminium are thus higher than for copper.

So generally speaking, copper is still the favoured current carrying medium for geothermal applications, other than for high voltage outdoor switchgear, which carries relatively low current.

Since copper can't be completely dispensed with, it needs to be protected in other ways.

2.1.2 Switching contacts

The switching contacts in circuit breakers, high voltage isolators and earthing switches, relays, contactors and other control gear are often coated with silver or cadmium to improve conductivity and/or durability. Silver is even less corrosion resistant than copper in the presence of H_2S. Cadmium doesn't corrode, but the gaseous product of its reaction with H_2S is toxic.

Therefore silver and cadmium are avoided if at all possible. Tin and gold are both immune to H_2S corrosion and so in geothermal applications copper switching contacts are often specified to have gold or tin plating. For some small control relays, hermetically sealed casings are available so that H_2S does not affect the contacts.

2.1.3 Power & control cabling

While fibre optic cabling is becoming more common for control systems, copper is still a common choice for conveyance of hard-wired protection, control and indication signalling. Since it cannot be dispensed with, other measures are taken to protect it, typically tinned conductors. Copper power cables are the preferred choice and in the larger sizes, the XLPE insulation provides an effective barrier against H_2S so that only the terminations need to be tinned. Particular care must also be given to all the cable glands used for the termination of cables as any nickel plated brass cable glands, which are commonly used outside the geothermal environment, will deteriorate rapidly when exposed to H_2S. Either stainless steel or nylon glands must be used in the geothermal environment.

2.1.4 Electronics

There is very little choice in materials for field instruments, transducers, switches, and control gear. All of it needs to be protected. This is normally done with special varnish coating called a « conformal » coating and is mandatory on all printed circuit boards used in the geothermal environment.

2.1.5 Grounding and lightning protection systems

Aluminium conductors can be used for grounding systems but because of their relatively low fault current rating compared to copper, and problems with joints becoming non-conductive over time, copper is still the favoured material for below-ground earthing systems. But when copper conductors are exposed to atmosphere, protective measures need to be taken.

Above-ground systems such as equipment grounding conductors and lightning protection systems may utilise aluminium as the joints are accessible and maintainable, however, tinned copper is still used for all earth bonding of above ground equipment as it is more ductile and easier to manipulate than the equivalent rating aluminium conductor.

2.1.6 Cable support systems

Aluminium and FRP cable support trays are readily available and have taken the place of galvanised trays in geothermal environments. However it is often still necessary to use hot dipped galvanised steel tray supports and fastenings for mechanical strength.

2.1.7 Galvanic reactions

The compatibility of two different metals may be predicted by consideration of their "Anodic Index". This parameter is a measure of the electrochemical voltage that will be developed between the metal and gold. To find the relative voltage of a pair of metals it is only required to subtract their Anodic Indexes. The smaller the difference in anodic index, the more compatible the metals are. If there is a large difference there will be a chemical reaction between the metals that will result in corrosion, exacerbated in a geothermal environment.

Zinc and copper have a large anodic difference, and so a competent designer avoids having galvanised surfaces in contact with copper, or uses bimetallic intermediate materials. But stainless steel is acceptably close in the Anodic Table, so stainless steel fasteners can be used to secure copper equipment.

Similarly aluminium is close to zinc in the Table and galvanised fasteners can be used to secure aluminium equipment.

2.2 Barriers

If the use of corrosion-susceptible materials cannot be avoided, then the first line of defence is to prevent the material coming in contact with the atmosphere.

Cables are adequately protected by their PVC sheaths, however cable terminations are not. If copper conductor is being used, the exposed part of the termination needs to be tinned prior to termination and a heat shrink PVC sleeve applied over the sheath and tinned conductor to protect the interface.

Some designers specify that small power and control cables plus all instrumentation cables are to be tinned throughout their lengths, which avoids the need for the heat shrink sleeving.

Busbars in indoor switchgear can carry thousands of Amps and will usually be of tinned copper composition. After fabrication, busbars and busbar joints can be provided with additional protection by sleeving with suitable PVC products or painted. Where high current carrying capacity is required, for example between the generator terminals and the generator transformer LV terminals, an isolated phase busbar (IPB) system is usually employed, using a combination of rigid aluminium conductors mounted inside clean air pressurised aluminium tubes, to prevent ingress of H_2S contaminated air into the IPB system, with tinned copper flexibles at the interface connections. Another example relates to the connections between the auxiliary transformer LV terminals and the incoming circuit breaker on the LV switchboard where the conductors can be installed as a non-segregated busbar system where the busbars are encapsulated in resin to give protection against any H_2S ingress.

Buried earthgrid conductors do not come in contact with the atmosphere. But above-ground equipment and reinforcing bar in concrete foundations need to be tied into the earthgrid to reduce touch potential risk and overall ground resistance. It is thus inevitable that connections to the earthgrid will come in contact with the atmosphere. These can be protected with tinning, suitable sleeving systems and/or suitable painting systems once fabrication is complete.

Some tradespeople swear by the use of corrosion inhibiting sprays such as WD-40, which can provide good protection for long periods (but not forever).

Electronic equipment, including circuit boards, must be protected with spray varnish products after assembly or be conformally coated during the manufacturing stage.

2.3 Encapsulation

Encapsulation is another form of barrier. If it is not possible to coat the susceptible materials, then exposure to atmosphere can be prevented by enclosing the materials in an air-tight enclosure.

It is common for designers to specify ingress protection (IP) ratings for outdoor junction boxes of IP56 or 66 (see IEC 60529 rating system for an interpretation). This is equivalent to a NEMA rating of 4.

2.4 H_2S absorption / adsorption

Media such as ferric hydroxide and activated carbon can be used in filtration equipment that removes H_2S from the atmosphere.

Such media can be used in bulk air-handling units to scrub the air in entire rooms and buildings, or in simple sachets placed in individual enclosures that are replaced from time to time.

2.5 Pressurisation

If enclosures containing susceptible equipment are held at a pressure higher than atmospheric using clean, dry air; then the possibility of H_2S ingress is prevented.

This system is often used for medium voltage isolated phase bus ducts using either aluminium and/or copper conductors to connect generators to circuit breakers and transformers. Clean, H_2S free, dry air is tapped off the compressed air system and fed into the enclosure. The clean dry air prevents condensation on the insulators inside the IPB and also prevents any corrosion of the components. Pressure is monitored and an alarm initiated if the system fails.

This system is also effective for outdoor enclosures containing equipment (such as contactors) that generates heat, and thus cannot be encapsulated. The air is fed into the enclosure and continuously bleeds out through the enclosure vents.

2.6 Positioning

The measures discussed so far are suitable for most field applications. But it is very difficult to adequately protect the most sensitive equipment – the switching and control gear, using the methods described so far.

Thus in geothermal power plants it is an almost universal practice to locate all switching and control gear in one building. Bulk air handling units are installed in this building to scrub the air fed into these rooms; both to filter out any H_2S and to keep the rooms at slightly higher than atmospheric pressure. Airlock spaces are installed at entrances to rooms with the most sensitive equipment to prevent any H_2S ingress.

This of course obviates many of the benefits of distributed control systems because all of the control nodes for the plant end up in the same room. It also creates cabling congestion and sizing issues because there are no remote switchboards close to plant loads. They are all housed together.

But this is the price of protecting sensitive, corrosion-susceptible equipment in a geothermal environment.

3. POWER HOUSE ANNEX VS. STAND-ALONE ELECTRICAL BUILDINGS

3.1 Electrical Annex

In most geothermal power plants the switchgear and control gear is centrally located in a two or three storey lean-to structure at the front of the power house called the 'electrical annex'. Because the annex is linked structurally to the power house columns, erection of the annex cannot begin until the power house structural steel has been erected.

It is preferable to have the electrical annex completely finished before installing any sensitive electrical and control gear into it. Thus all painting, floor finishes, doors, fire protection and air conditioning systems generally need to be installed and ready for service before equipment in mounted and cabling works begin. This avoids mechanical damage, water ingress, dust ingress and most importantly H_2S ingress.

But this staging limitation usually leads to the electrical and control system erection, cabling, testing and commissioning becoming critical path activities, with any delays directly impacting the commercial operation date.

Figure 2 shows the types of congestion issues that can arise with electrical annex type designs.

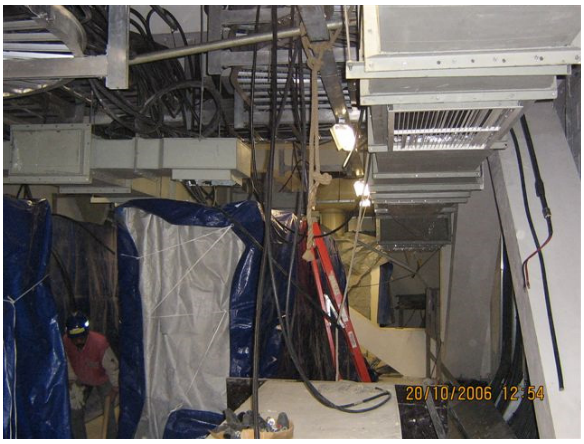

Figure 2: Example of congestion during erection activities in a typical electrical annex.

3.2 Stand-alone electrical and control gear buildings

At New Zealand's recently commissioned Te Mihi Geothermal Power Plant, designer Parsons Brinckerhoff chose an electrical building option more commonly used on binary geothermal and conventional thermal power plants to help smooth the staging of the electrical and control works, to reduce cable congestion and to obviate damage or corrosion to sensitive equipment during the construction of other plant.

This involved housing all of the electrical switchgear and control gear in several stand-alone buildings at the front of the power house rather than in an electrical annex connected to the power house. There was one building for each unit plus another for the common services electrical equipment. These were mounted on columns some 2.75 m off the ground to provide easy cable access from beneath. Each room was equipped with airlocks, air conditioners and H_2S filtration units.

The original intention was to assemble the buildings off-site, install and pre-wire all of the electrical and control equipment off-site, and then ship the buildings to site complete, ready for cabling.

Unfortunately the tight site layout, the panel spacing, the client specified room sizes and equipment redundancy requirements for this particular project resulted in stand-alone rooms too large for transportation, and so the buildings had to be erected on site. Nevertheless most of the planned benefits of having stand-alone buildings were realised, in particular:

- Because of space limitations, the power house columns and girts had to be erected before construction of the electrical buildings could begin, simply because the space was needed for crane access. Once that was complete however, the power house and electrical building erection activities were able to be carried out in parallel, relieving some of the critical path staging issues often experienced with traditional electrical annex arrangements.

- The design of the air handling and filtration systems was considerably simplified.

- Sensitive electrical and control gear was not installed into buildings until they were substantially complete – thus the risk of mechanical, water, dust or corrosion damage was significantly reduced.

- Cabling congestion was relieved and easy cable access was provided beneath panels without complex and expensive trenching or ducting works. The majority of the cables were to the power house and these were routed on overhead cable ladders, however some interconnecting cables to other buildings and areas outside the power house were routed through underground cable ducts. Clashes with other building services such as air conditioning ducts were avoided completely. This considerably sped up the cable termination works.

See Figure 3 for photos of two of the completed stand-alone buildings.

Figure 3a: Te Mihi Unit 2 and Common Services electrical buildings.

Figure 3b: Cabling space.

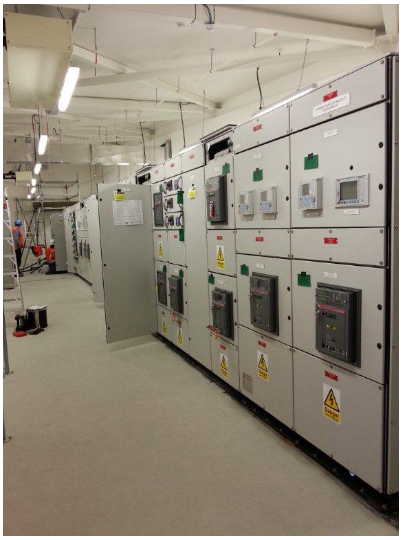

Figure 3c: Switchgear installation.

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