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ELECTRICAL PLANNING AND DESIGN FOR GEOTHERMAL POWER PROJECTS.

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ABSTRACT

This paper examines electrical planning required for successful geothermal electrical power generation projects. The importance of examining the impact of a proposed new generator connection on the operational performance of the existing electrical power system is outlined. Also discussed are electrical engineering design problems that can be encountered and solutions that have been used to enable operation in a geothermal environment

1. INTRODUCTION

The siting of a geothermal power project is determined by steamfield location, rather than by the location of electrical power demand. Hence an integral part of most geothermal projects is the provision of a transmission line and associated facilities to export the generated power away from the site. The connection of a new generator and the installation of the new line will invariably impact the operational performance of the existing power network. These impacts need to be considered at the preliminary planning stage of any geothermal project, alongside issues such as steamfield capacity and steam turbine sizing. If left to the point where construction is progressing, the resolution of issues and problems associated with the electrical connection may result in delays to the overall project or even inhibit export of electrical power and compromise commercial viability. One of the intentions of this paper is to raise awareness amongst geothermal power engineers of the important issue of electrical connection and power transmission.

Geothermal power stations are always sited in chemically hostile environments and unconventional electrical engineering methods are required to protect vulnerable equipment from chemical attack and corrosion. Another intention of this paper is to summarise some of these methods.

Geothermal power stations have other unusual requirements; this paper discusses some of these requirements and typical engineering solutions.

2. POWER SYSTEM STUDIES

During the preliminary investigation stage of a geothermal power station it is essential that electrical studies be carried out on the electrical transmission or distribution power system to which the station will be connected.

In all cases the engineer must determine the prospective fault level at the new power station after connection. This will tell what the highest expected fault currents will be at the station and will determine the required electrical fault ratings of the new equipment. Because of the effects of the power station being connected to the existing power system, the prospective fault duty of the system will increase, and this increased value should be checked to ensure the existing equipment could cope with the extra stress. It is possible that existing power system equipment, situated many kilometres distant from the proposed power station, may have to be replaced or uprated as part of the project.

A study must also be done to confirm that the existing power system can accept the proposed increase in real and reactive electrical load flow. There may be electrical limitations in the existing system that will prevent the flow of the generated power.

A third study that should be carried out is a transient stability study, which determines whether the new generator is able to maintain synchronised to the system following a system fault or step load change. It is also important to check if the system and voltage would remain stable should the new generator inadvertently become disconnected.

Other studies that can be done at the same time include investigating harmonic levels, system losses and voltage regulation.

The most appropriate method for undertaking such studies is to develop a computer model of the system under consideration and simulate the effects of the new generation on the system. Several software packages from a number of vendors are available for conducting such studies.

There are three distinct systems that must be modelled, and studies carried out to determine their interaction, compatibility and viability under various operational situations. The three systems are:

- The existing electrical distribution or transmission system.

- The new power station's electrical substation and cable or line connection.
- The new generators.

The existing electrical system owners should know all the electrical parameters of their own system, and may already have this information modelled with a suitable software package. These parameters may then easily be provided in software form. If not, data location and verification will be required and this can be time consuming. The new transmission connection's electrical parameters can be readily calculated, or estimated at the preliminary planning stage. Similarly the manufacturers can only provide the new generator's detailed characteristics once detailed design is complete, so at the preliminary planning stage typical known characteristics of similar machines will need to be used.

As the project progresses and contracts are let, more accurate parameters will become available, especially concerning the generators. This will enable more accurate simulation of the total combined interactive electrical performance of the three systems.

The aim of the power system studies is to ensure that the project is technically feasible from a power system standpoint, to identify any existing system reinforcements required and to ensure that the cost of such reinforcement is included in the project budget.

3. SYSTEM CONNECTION REQUIREMENTS

Most power system owners will have specific requirements for generators connecting to their system, and it is essential that discussions and negotiations take place with the system people at a very early stage to determine what their requirements may be. This could include such things as:

- Special electrical protection requirements.
- Protection telesignalling to remote substations.
- Communications circuits to a system control centre.
- Data circuits to a system control centre.
- Metering systems to specific accuracy and technical requirements.
- Specific substation or transmission line layout or design.
- Connection contract.
- Generating plant frequency performance.
- Generating plant governor performance.
- Generator power frequency range and reactive performance.
- Generator operating rules and regulations.
- Power quality and security of supply.
- Dispatching requirements.

All these issues will impact on design and should be clearly agreed well before the design or construction contract is let.

4. POWER TRANSMISSION

Electrical power can be transmitted from the substation via overhead transmission line or buried power cables. The cost of buried cables is more expensive than overhead transmission. For example to transmit 50 MVA underground will cost approximately seven times more than overhead. Cost is the usual deciding factor to go overhead. Sometimes with smaller amounts of power other factors like environmental or resource management may take precedence.

Buried power cables or overhead transmission lines will have to be provided with a route corridor between the substation and point of connection to the transmission or distribution system. Natural obstructions like native forests, rivers, bluffs etc, as well as man made obstructions like inhabited and industrial areas can provide difficulties. They should be considered and routes organised early in the project, as it generally requires using somebody else's land and this can get emotional, complicated and bureaucratic!

Route options include:

- Lease land from existing owners.
- Purchase land from existing owners.
- Arrange easement or right of way over properties.
- Be provided a line route by others
- Negotiate to share existing easement or right of way. (Road, rail, pipeline etc).

Negotiating to share an existing easement can be risky, as the easement owner could require complete access to it for maintenance of its own service. This could require an associated electrical circuit outage, entailing loss of transmitted electrical power and revenue for unspecified periods of time. However, planning and environmental investigation activities will nearly always be required together with possible lengthy negotiation and legal activities, all with their associated costs and possible time delays.

5. SUBSTATION

A substation will be required as part of most geothermal power stations, to transform the generated electrical power to a voltage suitable for transmission and provide switching, protection and connection facilities for the generators and transmission circuits.

In increasing cost order, the three main type options of HV substations are; Outdoor air insulated, Outdoor gas insulated, and Indoor gas insulated. The cheapest option will always be the outdoor air insulated type. However this will normally take up approximately six times the land area of a gas insulated substation (GIS). As outdoor space is rarely a problem with geothermal stations, GIS options are rarely seen. However the necessary substation land area must always be allowed for when laying out a geothermal plant.

The design of the substation including such features as number of busbars, equipment bay configuration, power transformer type number and rating, may be influenced by any of the following factors:

- Number of HV transmission lines.
- Number of generator connections.
- Required reliability.
- Budget.
- Transmission company requirements.

Major substation items like power transformers and high voltage switchgear will have manufacture and delivery to site lead times, similar to the major mechanical items like turbines. Therefore it is essential that the design of the substation proceed in parallel with that of the mechanical plant, to enable power export as soon as the turbines are commissioned.

There may also be a requirement for the installation of additional bay(s) of electrical equipment at a remote substation, where the new power export transmission circuit(s) are terminated. This will have significant cost and should be allowed for in preliminary planning.

6. REVENUE METERING

Accurate electrical revenue metering is essential for power generation projects. Because most projects are capable of importing and exporting electrical energy, facilities should be provided to meter and record active energy (kWh) exported and imported. In most instances it will not be sufficient to let the instrumentation arithmetically subtract kWh import from kWh export and record the remainder; because different tariffs will apply. In some situations it may also be applicable to meter and record reactive energy (kvar h) exported and imported, for the same reasons as above.

Depending on the amount of power being exported and the customer and generator's requirements, it may be necessary to also provide backup revenue metering. This is usually to the same accuracy as the main metering.

The revenue meters and auxiliary equipment are usually required to be stringently tested after installation and before commissioning, to meet National Codes and regulations together with generator or customer requirements. This usually requires the use of special test gear and appropriately certified personnel, either of which may not be available when required if not pre-arranged and scheduled into the overall construction programme.

7. PRIVATE POINTS OF SUPPLY

Should a geothermal power station be built at a remote site with a limited or non-existent electrical power reticulation system, there is sometimes the opportunity to supply consumers close to the station with their own electricity supply directly fed from the power station. This could be supplied from the generator bus via a circuit breaker and transformer. Conventional power distribution technology would be applicable, although special protection arrangements may be necessary.

In this case it is usually easier and cheaper for the customer to discontinue taking supply from the utility and take all supply from the power station, with the ability to switch back to the utility if required. Taking supply from both the power station and the utility on the same circuit at the same time can become complicated and is not usually done.

The supply to the customer from the power station should be much more reliable than that from the utility, and this factor could be used in marketing the sale of supply to prospective customers.

The rules and regulations concerning a generator providing supplies to private customers, while at the same time being connected to a transmission or distribution system which would normally provide this supply, should be checked as this may not be permitted in some countries.

8. ISLAND OPERATION

Island or stand-alone operation can occur where a power station becomes disconnected from the electrical power transmission or distribution system it is exporting power into, usually due to a fault or disturbance on that system. The turbine/generator however manages to continue in service generating reduced power for its own auxiliary equipment. Another way islanding can occur is if the power station is black started, with no connection to the power system, and continues to generate power for its own auxiliaries only. If either of these situations is a requirement then there must be facilities available at the power station to enable the islanded system to be synchronised with the power system to enable full station output to be exported. This may not be possible if synchronising equipment is only provided on the generator circuit breakers.

9. AUXILIARY POWER

Electrical power is necessary for the plant auxiliary equipment, control room, and steam field equipment during generator off line situations, generator start up situations, normal generating situations and generator run down. This power is usually obtained via auxiliary transformer(s) supplied from the system. Should the power station become disconnected from the system, and Island generation not be occurring, there will still be a requirement for auxiliary power to operate such things as turbine/generator main lube oil pumps, steam field reinjection pumps and essential control room power during the turbine run down period.

There has to be an alternative source of auxiliary power, apart from the DC battery and system connection, for run down and off line situations. A low voltage supply from a local power utility or an emergency generator with automatic start up and change over to provide power to a dedicated LV emergency services motor control centre is the norm.

Emergency generators are usually not rated for Black Start situations, where the auxiliary load requirements are larger. Should Black Start be required, an appropriately sized Diesel generator should be included.

Alternative sources of auxiliary power should be determined at the beginning of the project at the preliminary electrical design stage. Retrofitting later can be expensive.

10. DIESEL ENGINES

Emergency and Black Start Diesel Generator engines need to be periodically operated near full mechanical load to ensure that they will function at full load when required in an emergency. Starting them periodically and running unloaded for short periods will not guarantee that they will function correctly at full load when required. Consistently operating unloaded will damage the engines by causing the cylinder bores to become glazed and injectors clogged. A convenient way of fully loading such engines for testing purposes is to synchronise them to the system and generate full rated electrical output into the system. This of course requires synchronising equipment for the generator, and is not usually provided. The small extra cost of providing synchronising equipment should be more than compensated for by increased reliability of the engine and auxiliary power.

11. STEAM FIELD ELECTRICAL SUPPLIES

Geothermal power station steam fields generally require a reliable electrical supply to be distributed to the various well and bore heads to provide power for pumps, control and instrumentation. The amount of power and transmission distance usually necessitates distribution typically between 6 to 20 kV, with transformers at each well head or point of supply. Conventional power utility distribution technology is usually utilised for this purpose with overhead lines and pad mounted transformers being common. Buried power cables are often not used because of cost and high ground temperatures.

Well and bore heads may require relocation during the life of a steam field and power station. To accommodate this requirement the use of portable power distribution equipment such as containerised substations and ring main units, is common.

Steam field electrical power supply is usually not taken from the local power utility because a more reliable and less costly supply can be provided from the power station itself. In some instances there may be no local power utility to take supply from.

12. EARTHING

Geothermal power stations and the associated substation and steam field distribution system will always require some form of buried earthing system. The purpose of the earthing system is to:

- Enable electrical equipment protective devices to operate correctly.
- Make the site safe for people under electrical fault conditions.
- Make the site safe for sensitive electronic equipment, under electrical fault conditions.

During transitory electrical earth fault situations, especially in the substation, fault current will flow from the faulted equipment, through the earth and raise all earthed equipment to a high potential. During this situation earth potential gradients will be generated in the vicinity of the power station. If the earthing system is incorrectly designed, a person stepping in this area could experience dangerous "step" voltages across the feet, or if touching earthed equipment could experience dangerous "touch" voltages. The earth potential voltage can be transferred to any conductor in the vicinity of the power/substation earthing system. Metal steam pipes, electrical cable sheaths and armouring, railway lines, service pipes, communications cables, metal fences and other means can transfer these high voltages many tens of kilometres from where they were generated, and be fatal to man, beast and sensitive control, data and communications equipment.

Normally transferred potentials in pipes are eliminated with the provision of a suitable section of electrically insulated pipe. However this cannot be done with geothermal steam pipes due to the high temperatures and pressures used. Therefore other appropriate earthing methods must be designed to eliminate these dangers.

The consequences of removing valves and sections of steam piping for maintenance and the possibility of dangerous fault induced voltages occurring across the breaks, should also be considered in the overall earthing design.

13. BURIED POWER CABLES

Power cables direct buried in the ground and continuously carrying high currents cause heat to be generated in the cables. To prevent cable damage, the surrounding ground must adequately dissipate the heat. To calculate the current carrying capacity of the installed cables a knowledge of the thermal resistivity of the ground is required. It has been common practice to assume a typical ground thermal resistivity of 1.2° K.m/W, and that it will remain at this value over a wide range of moisture content, without carrying out either field or laboratory tests to ascertain what the actual value is. If continuously loaded power cables are rated on this basis and the actual site conditions are different, the cables may overheat and fail.

Some NZ power station soil tests have established that volcanic soil can have thermal resistivity values much higher than 1.2° K.m/W, and that resistivity can vary significantly due to moisture content. A high soil thermal resistivity contributed to the 1998 Auckland 110 kV power cable failures and resulting central business district power black out. These cables were installed in volcanic soils. Geothermal power stations may be sited on soil which is volcanic in origin, so it is necessary for actual soil resistivity tests to be carried out to enable proper rating of buried power cables.

Another important factor involved with rating buried power cables is the ground temperature. Figure 1 shows a typical rating curve for a high voltage cable and how the current rating of the cable is proportional to ground temperature. In this instance the cable is 100% rated for a ground temperature of 15^0C and 0% rated for 85^0C. The actual ground temperature should be carefully considered when sizing buried power cables in a geothermal environment; it may be much higher than the average ground temperature in normal situations. Hence cables sized for normal ground temperatures but installed in a geothermal environment could easily be over-rated and fail prematurely.

14. HYDROGEN SULPHIDE CORROSION

Corrosion of bare copper electrical equipment in a geothermal environment from hydrogen sulphide contamination is a potential problem. Large copper current carrying items like bus bars, clamps and conductors, flexible connections and screwed copper control wiring connections are vulnerable. H_2S will also permeate PVC insulation of control wires and plastic casings of integrated circuits, to corrode the copper conductors within.

A related problem is cadmium-plated items like nuts and bolts, which are prone to corrosion in an H_2S environment and produce highly toxic corrosion residues.

Such problems have been overcome by:

- Use of tinned and epoxy painted bulk copper, outdoors.
- Use of corrosion resistant materials such as aluminium and stainless steel.
- Use of heat shrink material on exposed copper.
- Use of tinned copper wires.
- Varnishing and painting indoor items.
- Epoxy encapsulation of small components.
- Careful selection of paint systems and sealing gaskets.
- Epoxy painting of exposed items.
- Avoiding cadmium plated items.

Indoor electrical equipment, particularly electronic printed circuit boards with plug in copper connections associated with control, instrumentation and protection equipment is particularly vulnerable to corrosion and failure. Methods of overcoming this problem include:

- Specification of H_2S rated instruments and connections.
- Specification of gold plating on printed circuit board connections.
- Placing all sensitive equipment in a positive pressurised and H_2S filtered room and controlling the temperature and humidity.
- Provision of H_2S resistant enclosures, around isolated sensitive equipment, with anti-condensation heaters.

15. POWER CABLE INSULATION

Cross-linked polyethylene (XLPE) is commonly used as an electrical insulating material for power cables. Tabata et al., (1971) found that XLPE cables immersed in water, into which H_2S had dissolved, enabled the H_2S to permeate through the polyethylene insulation and on contacting the copper conductor, produce copper sulphide which crystallised and fused into the insulation. This formed conducting sulphide trees and caused electrical failure of the cables.

A similar situation could exist in a geothermal environment if XLPE cables are laid in poorly drained cable trenches or direct buried in the ground, where heavier than air H_2S could accumulate and dissolve in rain water surrounding the cables. Typical methods of overcoming this problem include the use of aluminium conductors for all power cables, and ensuring they are mounted in air above ground level.

16. ENVIRONMENTAL

There will usually be outdoor oil immersed transformers for power export and auxiliary requirements. The possibility of the transformers becoming damaged or improperly operated/maintained and causing bulk oil spills should be considered. The designer should consider where the oil can go and what can happen to it; ie will it burn or get into the eco-system? Some countries have stringent environmental regulations requiring spilt oil to be automatically collected to prevent contamination of the environment. If this is necessary then it will normally be required to separate any ground or rain water from the spilt oil as well. This will require dedicated equipment.

The distribution transformers on the steam field could also possibly leak smaller amounts of oil to the environment. It is generally accepted that it is impractical to design for these small outdoor units to prevent oil contamination; with most authorities requiring clean up procedures to be in place should a spill occur.

Most modern high voltage circuit breakers are now of the Sulphur Hexifluoride (SF6) pressurised type. SF6 is a heavier than air, inert colourless and odourless gas which does not decompose or break down if released into the environment. Normally during the life of these circuit breakers dismantling for maintenance or repair will not be necessary, but should this be required, thought should be given to what to do with the SF6 gas. Sometimes SF6 gas is released to the environment when the circuit breakers are dismantled for maintenance, and new gas used to refill them after reassembly. For larger plants, consideration should be given to having equipment on hand to filter, store and recycle the gas.

17. ELECTRICAL SITE SUPERVISION

Electrical construction, testing and commissioning work may be part of a manufacturer's turnkey contract, or a project construction contractor may carry it out. Generally speaking the contractor will have won the work on the basis of the lowest price and shortest completion time, and be under financial, time and possibly resourcing pressures. The temptation to take shortcuts will be present. The consequences of allowing such shortcuts to take place can have major implications on the short and long term viability of the project.

Electrical engineering supervision of the construction, testing and commissioning phase of the project, as the work is occurring, by an experienced independent electrical engineer is necessary. Mechanical engineering supervision usually occurs, but the electrical side is sometimes overlooked. This should not occur as Mills (1997) reports the electrical component cost of a typical geothermal power station is very similar to the mechanical component cost.

18. CONCLUSION

Geothermal power stations are usually an order of magnitude smaller than conventional power stations and because of this, the electrical system connection issues are not always given sufficient planning attention.

For a successful and trouble free completion of a geothermal power generation project it is essential that electrical engineering input be included at the preliminary planning stages and continue through detailed design and site supervision to commissioning, in conjunction with the mechanical, civil and chemical engineering input.

19. ACKNOWLEDGEMENTS

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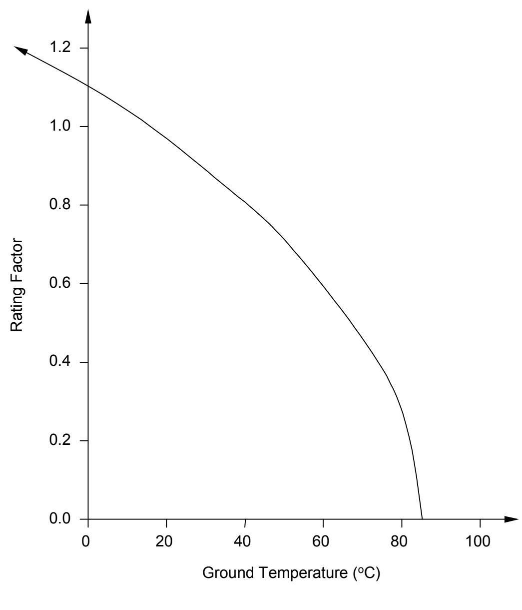

Figure 1: Ground Temperature Effect