Proceedings 20th NZ Geothermal Workshop 1998

ELECTRICAL ENGINEERING ASPECTS OF GEOTHERMAL POWER PROJECTS

I.V.W. HUNT[1]

[1]DesignPower, PB Merz & McLellan (NZ) Ltd., Wellington, NZ

SUMMARY – This paper outlines typical practical electrical engineering design and planning aspects necessary for successful geothermal electrical power generation projects. Also discussed are electrical engineering problems that can be encountered and solutions that have been used to enable operation in a geothermal environment.

1. INTRODUCTION

A significant proportion of geothermal electrical power generation projects have electrical output capacities of a magnitude less than conventional power stations. The siting of these projects is usually determined by steam field locations, not electrical power demand. Hence there is usually a necessity of transmitting small to medium blocks of electrical power, as part of the project. One of the intentions of this paper is to raise awareness of the important issue of electrical connection and transmission of power away fiom the power station. These issues need to be considered at the preliminary planning stage along with such considerations as steam field 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 in the overall project or even inhibit export of electrical power and compromise commercial viability.

Geothermal power stations are always sited in chemically hostile environments and unconventional electrical engineering methods are required to protect vulnerable equipment fiom 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.

2.0 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 equipment may have to be replaced or uprated).

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 synchronism with 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 exist fiom a number of vendors 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, laborious data location and verification will be required. 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. So at the preliminary planning stage typical known characteristics of similar machines can 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 forecasts 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 fkom a system standpoint, to identify any existing system reinforcements required and to ensure that the cost of the reinforcement is included in the project budget.

3.0 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 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 construction contract is let.

4.0 POWER TRANSMISSION

Electrical power transmitted fiom the substation can be 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. This should be organised early in the project as it generally requires using somebody else's land and this always gets 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.
- Negotiate to share existing easement or right of way.
- Be provided a line route by others.

Negotiating to share an existing easement can sometimes easily be arranged especially along existing railway line routes and road ways. 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.

5.0 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.

There are three main type options of HV substations and these are shown below in increasing cost order:

- Outdoor, air insulated substation.
- Outdoor, gas insulated substation.
- Indoor, gas insulated substation.

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.

6.0 REVENUE METERING

Accurate electrical revenue metering is essential for power generation projects. Because most projects are capable of importing and exporting electrical power, facilities should be provided to meter and record real power (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 power (kVArh) exported and imported, for the same reasons as above. It should be noted that presently in New Zealand kVArh are not a commercial and tradable commodity, but this is likely to change in the future.

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.

7.0 PRIVATE POINTS OF SUPPLY

Should a geothermal power station be built in 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 fkom 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 fiom the power station, with the ability to switch back to the utility if required. Taking supply fiom 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 fiom 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.

8.0 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.

9.0 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 fiom the system. Should the power station become disconnected fiom 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 fi-om the DC battery and system connection, for run down and off line situations. A low voltage supply fiom 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.

10.0 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 them 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.

11.0 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 rarely used due to the high temperature of the ground.

However there is the problem of well and bore heads possibly being moved during the life of the steam field and power station. The power distribution system can accommodate this requirement by utilizing portable equipment such as containerised MV/LV substations and ring main units.

Steam field electrical power supply is usually not taken fiom 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 fiom.

12.0 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 electrical earth fault situations, especially in the substation, fault current will flow fiom the faulted equipment, through the earth, to a remote earth point some distance away. As the earth has finite resistance, voltages will be developed for the duration of the fault. While the fault persists the entire earthing system and everything connected to it will rise in potential with respect to remote earth. This can be of the order of tens of thousands of volts and is known as "earth potential rise". 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 walking or stepping in this area could experience fatal "step" voltages across his feet. Similarly a person with feet on the ground in this area and also touching earthed equipment could experience fatal "touch" voltages. While this earth fault condition persists, the earth potential rise voltage will be transferred to anything electrically connected to the power/substation 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 equally 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.

13.0 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. Calculations can be carried out to determine the current carrying capacity of the installed cables and, among other things, this requires knowledge of the thermal resistivity of the ground. It has been common practice to assume a typical ground thermal resistivity of 1.2° K metres/Watt, 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. However 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 it can vary significantly due to moisture content. It has been reported in the media that a high soil thermal resistivity contributed to the Auckland CBD 110 kV power cable failures and resulting 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.

14.0 HYDROGEN SULPHIDE CORROSION

Corrosion in a geothermal environment from hydrogen sulphide contamination is a continuous problem.

Large outdoor exposed, heavy copper current carrying items like bus bars, clamps and conductors are particularly vulnerable, as excessive corrosion will reduce the cross section area and increase the resistance, resulting in excessive heating and possible premature failure. Another item prone to this type of failure is multi-layered flexible copper straps used for connections in outdoor HV disconnector switches and for bus bar flexible connections.

Corrosion of cadmium plated mild steel items, like nuts, bolts and washers will produce highly toxic residues. Such items should be avoided.

Methods of overcoming corrosion problems include:

- 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.
- Mild steel galvanising and epoxy painting.

Indoor electrical equipment, particularly electronic printed circuit boards with plug in copper connections associated with control, instrumentation and protection equipment are particularly vulnerable to corrosion and failure. Methods of overcoming these problems 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 control cubicles with anti-condensation heaters.

15.0 ENVIRONMENTAL

There will usually be outdoor oil immersed power transformers for 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 bum 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 fiom 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 modem 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.

16.0 ELECTRICAL SITE SUPERVISION

Electrical construction, testing and commissioning work may be part of a manufacturer's turnkey contract, or it may be carried out by a project construction contractor. 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.

17.0 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 fiee 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.

18.0 ACKNOWLEDGEMENTS

The assistance of Martin Beech, Brian White and Geoff Brown in the preparation of this paper is greatly appreciated.

19.0 REFERENCES

Bradford, Hon. M. (1998). Ministerial Inquiry into the Auckland Power Supply Failure. ***Media Release,*** 21 July.

Coulter, R. (1997). Planning Studies for Connection of Embedded Generation to Distributed Systems. ***Proc. EEA National Conference,*** Wellington.

Deller, R., and Hunt, I. (1991). Design of Substation and Power Station Earthgrids. ***Proc. ESA Regional Conference,*** Wanganui.

Mills, T. (1997). Matching the Field to the Plant. ***Proc. 19th N.Z.*** Geothermal Workshop. University of Auckland.

Power Engineering Journal, February 1995.

Ryan, G. (1998). Taranaki Combined Cycle Project: 220 kV XLPE Cable Link. Proc. ***EEA National Conference,*** Auckland.

Walker, H.P. and Beech, M.T. (1988). The Refurbishment of Electrical Plant Operating in a Geothermal Power Station. Proc. ***IEC Conference,*** London.