Large scale integration of geothermal energy into the Australian transmission network

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Enhanced geothermal systems are expected to have significant potential for generating electricity in Australia, however two types of challenges need to be addressed. One is technological developments in converting the heat from hot granites 4-5 km below the earth's surface to electricity. The other is efficiently delivering the generated electricity to end users located far away from the generation zone. The aim of the transmission research program of the Queensland Geothermal Energy Centre of Excellence (QGECE) is to investigate the technical aspects of connecting remote geothermal power plants to the existing high voltage transmission network. This paper presents an overview of the transmission program by briefly explaining the challenging issues of large scale integration of geothermal energy into the Australian network and introducing the research projects of the transmission program. Details of each study can be found in the cited published papers.

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1. Challenges

The following subsections briefly discuss the challenges of large scale integration of geothermal energy into the Australian electricity network.

1.1 Remote location

Major geothermal energy sources in Australia are located in remote areas far away from the high voltage transmission network. Hence, long transmission lines are required to deliver the power to major load centres. Apart from huge investment in building new lines, the operation of long transmission lines carrying bulk amount of power has technical issues such as voltage and small signal stability.

One of the challenges of transmitting power through long HVAC transmission lines is power losses. Ohmic power losses increase significantly when length of the line increases. This means the generation of geothermal power located in remote areas should be large enough to overcome the significant power loss problem.

1.2 Uncertainties

This section explains major uncertainties involved in the future planning for transmitting large scale geothermal power to the national grid.

Generation technology

Extracting heat from hot granites located 4-5km below the earth's surface to generate electricity is the main concept behind enhanced geothermal systems. Small scale power generation based on this concept has been successfully proved in 2009 (Geodynamics 2009). It is estimated that the Cooper and Eromanga Basins could generate 4000 MW power to supply base-load by 2030. There are uncertainties in the technology required to realise this potential and also make it competitive against electricity from other sources.

Emission trading scheme

Currently in Australia, similar to other electricity markets, the generation cost of electricity from renewable sources is comparatively higher than that from fossil fuels. Emerging carbon pricing and/or emission trading schemes are expected to change this trend and makes the cost of electricity from renewable sources of energy competitive against that from other sources such as conventional coal power plants.

Transmission regulatory frameworks

Major renewable sources of energies such as geothermal are located in remote areas from the existing transmission infrastructure. The huge investment cost of building long transmission lines is a hurdle for large scale integration of geothermal energy (and other renewable energies) into the national grid. Policy changes in current connection arrangements for remote renewable generators are required to facilitate large scale penetration of renewable energies and meet the renewable energy target by 2020. Approval of proposals such as *scale efficient network extensions* can be beneficial to the geothermal industry as well as other renewable generators.

2. Industry engagement

Planning experts from Powerlink Queensland and the Australian Energy Market Operator (AEMO) are members of an industry advisory committee of the transmission research program. The role of this committee is to provide technical advice and feedback for the research projects (QGECE 2010).

To determine the most efficient connection options for connecting large scale geothermal energy into Queensland network, Powerlink Queensland in 2010 provided the QGECE with the Queensland transmission network power flow data based on a confidentially agreement. As part of the current transmission research program, possible scenarios of connecting prospective geothermal power plants to the Queensland electricity grid are being investigated. In this study the most efficient transmission option for each scenario is determined by taking into account the optimum voltage level, transmission line configuration and transmission technologies (HVAC versus HVDC).

Also, in order to be able to explore the connection options to South Australia, QGECE is in contact with ElectraNet to access the South Australia's network data.

Small scale geothermal energy is one of the renewable sources of energy that can be used to supply remote area off-grid electricity networks. To overcome the capacity limit of the geothermal reservoir to supply the peak demand, other renewable sources of energy such as solar together with diesel and energy storage can be used. In addition, demand response programs can also be utilised to maintain the balance between demand and supply. Currently authors are conducting a research project for TransGrid, the transmission service provider in New South Wales, to investigate the impact of demand response programs on transmission network planning.

3. Transmission research program

The aim of the transmission research program is to analyse large scale integration of geothermal power scenarios into the Australian electricity network with acceptable reliability and economical way considering foreseeable carbon pricing schemes.

The following sub-sections briefly introduce the main focuses of the transmission program. Details of each project can be found in (Bui et al., 2011; Eghbal et al., 2011; Eghbal et al., 2010; Hasan et al., 2011a,b; Nguyen et al., 2010a, b; Nguyen et al., 2011). It should be mentioned that the feasibility of the developed methodologies are first validated by implementation on simplified test power systems. The ultimate aim of the transmission project is to apply the developed methodologies to the Australian electricity network.

3.1 Voltage stability

One of the challenging issues of operating a long transmission line is voltage stability. When the line is transferring bulk amount of power, any voltage instability problem could jeopardise the security of the network. The stability project of the transmission program addresses steady state voltage stability, small signal stability and transient stability issues.

Voltage stability studies on Australian South East (SE) 14 generators test system show that bipolar HVDC transmission lines are more stable compare to HVAC (Nguyen et al., 2010a). Also it has been demonstrated that stability of the HVDC interconnection is not deteriorated when the length of the line increases. On the other hand, the stability margin of HVAC interconnection decreases proportionally when the length of the interconnection increases.

Inter-area oscillations are caused by interactions among large groups of generators at two ends of an interconnection. Small signal stability analysis on HVAC interconnections shows that the inter-area mode becomes less stable when the length of the interconnection increases (Nguyen et al., 2010b). Simulation results of connecting a remote generator to the simplified South East Australian power system (Gibbard, 2010) have shown that power system stabiliser and power oscillation damping controller can effectively damp the oscillations (Nguyen et al., 2011).

To improve the transient stability of the simplified South East Australian power system (Gibbard 2010), a new supplementary control for current source converter HVDC has been developed (Bui et al., 2011). Three phase balanced fault analysis has shown that the proposed rectifier controller model improves the transient stability of the system. Also, it has been observed that the connection point of the HVDC interconnection has a significant impact on the power loss.

3.2 Reliability analysis

Geothermal energy is a base-load renewable source of electricity. Large scale integration of geothermal energy can affect the reliability of the network. Basically, connecting a large base-load power plant improves the generation adequacy. Distance between the generation zone and the load centres, transmission configuration and technology (HVAC/HVDC) are factors that affect the reliability. There are few candidate connection points in each state for connecting the prospective geothermal generation zone in Innamincka to the national transmission network. Random outages in the long distance lines carrying bulk amount of power can seriously deteriorate network reliability and result in power flow congestion in other parts of the network. Price spikes in the electricity market are also one of the consequences of transmission congestion.

The aim of the QGECE's reliability analysis project is to develop a probabilistic reliability analysis tool for studying the impacts of future large scale geothermal generation capacity on the Australian electricity market. Simulation results on IEEE 24 bus reliability test system confirm that the following issues have an impact on the locational marginal price of the electricity in the electricity market (Hasan et al., 2011a):

- connection point of new renewable generators
- configuration of future network expansion
- generation technology
- future load growth

Further analysis on possible transmission configurations has proved that proper selection of the hub location (in case of connecting remote generators to a network) could be useful to justify the investment cost. Moreover, considering emission cost in the market benefit analysis also makes remote renewable generation options more competitive against traditional sources of generation (Hasan et al., 2011b).

3.3 Transmission expansion planning

Two types of transmission projects are required to transfer base load power from prospective geothermal power plants to major load centres. One is extending the existing transmission network to reach the geothermal generation zone (in Cooper Basin) and the other is increasing the power transfer capability of the existing interconnections. The Australian Energy Market Operator (AEMO) has identified a few connection points in South Australia, Victoria, New South Wales as well as Queensland (Silva and Robbie, 2009). The proposed transmission line between Innamincka and South Australia has the shortest distance (about 450 km). However, the current capacity of the interconnections between states and future wind generation expansion plans in South Australia make it impossible to deliver bulk amount of geothermal power from this state to major load centres in Victoria and New South Wales without major transmission augmentations.

Each transmission project requires an enormous investment cost and takes a considerable amount of time. Therefore, determining the most efficient transmission expansion scenario is very important to AEMO, transmission service providers as well as renewable energy generators including the geothermal industry.

The transmission expansion planning project aims to determine the optimal location and size of the new transmission lines considering possible generation expansion scenarios and forecasted demand. The objective is to economically upgrade the network in order to supply future demand in the most reliable way. In this project, the problem is formulated as a mixed integer nonlinear programming problem and solved by using meta-heuristic optimisation techniques such as genetic algorithm (GA), particle swarm optimisation (PSO) and shuffled frog leaping algorithm (SFLA) (Eghbal et al., 2011). Simulation results show that not only optimal location and number of new transmission lines are important but also increasing the voltage level of new lines can reduce the total cost by reducing the power losses and enhancing available transfer capability. In systems with an uneven distribution of generation and load centres, the impact is more significant.

Implementing some form of carbon pricing is expected to make the generation cost of electricity from renewable sources more competitive to that from fossil fuels and consequently facilitates the penetration of renewable generators into the current power system. As such a change in the future generation portfolio will affect transmission planning, it is important to consider the uncertainties associated with the carbon price and emission trading schemes. Currently, authors are developing a multi-objective planning framework to address the impact of CO_2 price on transmission expansion planning.

3.4 Connection to Queensland

The transmission network in Queensland is a HVAC network with 330 kV, 275 kV and 132 kV lines. Powerlink recommended constructing a new Halys to Blackwall 500 kV transmission line in order to address the forecasted thermal and voltage stability limitations in south east and west Queensland (Powerlink 2009).

To investigate the feasibility of connecting large scale geothermal power plants in Innamincka to the Queensland network, the current 275 kV substation in Western Down is considered as the connection point. It is also assumed that the 500 kV network in Queensland is in place. Different scenarios for connecting 1000 MW and 600 MW geothermal power are chosen and then analysed. Simulation results show that 500 kV double circuit line and 275 kV double circuit line are the most likely HVAC options for connecting 1000 MW and 600 MW geothermal power to the Queensland network, respectively. Since geothermal power plants are base load generators, active power loss and reactive power compensations are important issues. Preliminary results show that it is economical to increase the voltage level of the new interconnection up to 500 kV and consequently increase the investment cost in order to reduce the operating cost over the life time of transmission lines.

The feasibility of using recent HVDC transmission technologies will also be studied. Recent technological developments as well as lower power loss make HVDC a competent option to

HVAC for transmitting bulk amount of power over long distances.

4. Conclusions

Connecting remote geothermal generation power to the national grid is a challenging issue. Large investments are required and different uncertainties are involved in the transmission planning problem.

Thertansmission research program at the Queensland Geothermal Energy Centre of Excellence focuses on addressing the stability and reliability issues of connecting remote large scale geothermal power plants to the national grid. Feasibility of HVAC and HVDC transmission technologies are being investigated.

Uncertainties affecting the transmission project are identified and being considered in developing a new transmission planning framework.

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