A Review of Geothermal Power Generation

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1. Introduction

Geothermal power generation was first experimented in Italy in 1904 as a water-binary cycle system that used a reciprocating steam engine, very different from the flash cycle systems of today. In 1923, also in Italy, a system which introduces geothermal steam directly into a steam turbine was tested for the first time.

Since then, this system has become the major means of geothermal power generation. Many geothermal power plants which use flash cycles (natural steam, single flash or double flash) have been built in countries where geothermal resources are abundant such as New Zealand, the Philippines, the USA and Japan. According to a presentation at the World Geothermal Congress of May, 1995 in Florence, Italy, the total capacity of geothermal power plants in the world is 6,800MW as of today. Of that number, Fuji Electric has supplied 1,400MW.

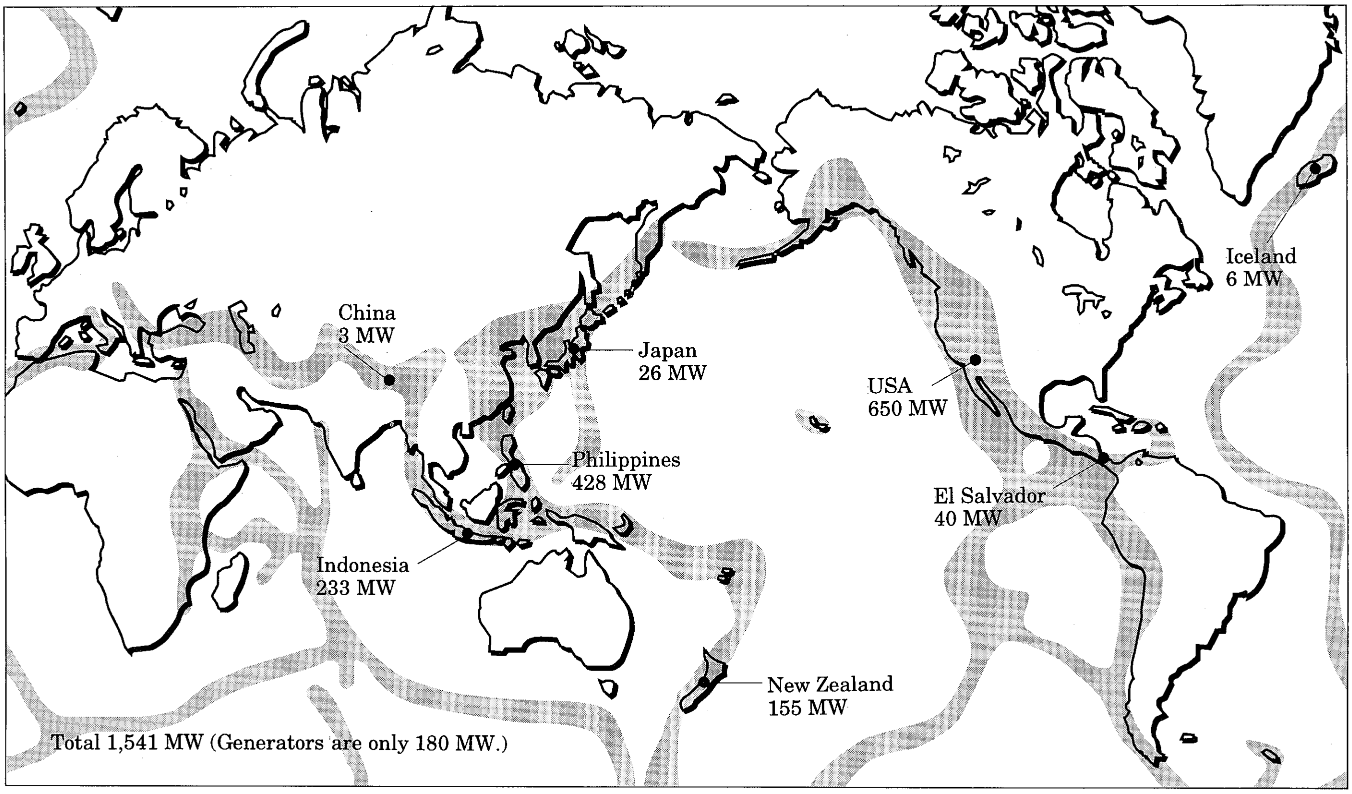
2. Current Status

Features of geothermal power generation, that it is clean and recyclable, are widely known. Since there is no combustion of fossile fuels which emit oxides of nitrogen or sulphur, geothermal power generation contributes to the conservation of the environment. Geothermal steam was originally rain water which penetrated deep underground and was heated by magma. Hot water from wells is also returned to the earth after separated from steam, which is to be used for power generation. This completes a natural recycling system. Although geothermal energy cannot be transported like a fossil fuel, it is enthusiastically being developed in countries where geothermal resources are abundant. Figure. 1 shows geothermal zones in the world and the capacity of Fuji Electric installed geothermal units. Table 1 shows the capacity of countries in both 1990 and 1995. As you can see from this table, the development of geothermal power generation is particularly active in those countries which have no petroleum resources such as the Philippines, New Zealand and Italy. In the USA which has the largest installation of geothermal power plants in the world, and at the same time is one of major oil producing countries, geothermal power generation is recognized as an economical and environmentally benign means of power generation whose resources are abundantly distributed in the western states, especially in California, where the provision of laws such as PURPA have paved the way for the use of new types of energy. Although Indonesia is blessed with fossil fuels such as oil and natural gas, it is aggressive in the development of geothermal resources because of the steep increase in domestic energy consumption that accompanies economic growth. The sale of fossil fuels is also a valuable source to obtain foreign currencies. If present development plans are realized, Indonesia will have the largest capacity of geothermal power generation in the world by the early twenty first century.

In the Philippines and Indonesia, geothermal power plants used to be built by national utilities such as NPC (the Philippines) and PLN (Indonesia). However, it is becoming more popular to build a plant under a BOT (Build, Operate and Transfer) type contract where a foreign developer and the national utility sign an ECA (Energy Conversion Contract) or PPA (Power Purchase Agreement). This system helps to accelerate the construction of power plants by attracting foreign developers, particularly American developers who have many domestic experiences. In this system, either a governmental body such as PNOC (the Philippines) or PRETAMINA (Indonesia) develops and maintains geothermal fields to supply steam and developers build power plants, or a private developer does everything from drilling wells and constructing pipelines to building the power plant. In either case, the main tendency is for the developer to enter into an EPC (Engineering, Procurement and Construction) type contract with a supplier, where the supplier is the single body responsible for the completion of the power plant. In order to receive financing from monetary institutions, it is essential to have a single responsible entity as the main contractor rather than having multiple subcontractors.

Fuji Electric, a leading manufacturer of main equipment, recognizing the needs of geothermal devel-

Fig.1 Worldwide geothermal zones and power plants supplied by Fuji Electric



opers, has become increasingly prepared for total plant engineering. For the currently in progress Malitbog Geothermal Project in Leyte, Philippines, Fuji Electric (along with Sumitomo Corporation as the main contractor) is working on the project under a full turnkey basis which includes construction, civil engineering work, manufacturing, procurements, installation and commissioning of the plant which consists of three 77.5MW units. In this case, the only data Fuji was given were the steam conditions at the plant boundary, the site meteorology, and the customer's required net plant output. Fuji started the engineering work by determining the design wet bulb temperature. This has a large influence on the plant economy and performance. Then, design conditions were specified for the main equipment and each sub-system. The ultimate goal of plant engineering is to realize a geothermal power plant which is reliable, highly efficient, economical, and at the same time has a minimum influence on the environment.

3. Technological Aspects

In latter half of the 1980s, several large scale units, 110 to 150MW capacity units consisting of two 55MW class turbines coupled in tandem, were constructed in the Geyser area of northern California to lower the cost of generated power. These large units can certainly help to reduce the plant construction cost per kilowatt, but run the risk of causing a shortage of steam to generate the rated capacity. In fact, the last 150MW unit was manufactured and delivered but never installed because of the shortage of resources. A large unit is especially unsuited for an IPP (Independent Power Producer) who sometimes relies on only one unit for its revenue, because of possible shut downs of the total power plant due to periodical overhauls or trouble. Therefore, if the developer has enough steam to support 150 MW, it is wiser to install three 50MW units or two 75MW units to increase the plant operational flexibility.

On the other hand, there are increasing demands to shorten the period of site work. Responding to this demand, Fuji Electric has standardized so-called skid mounted type turbines and has delivered several of them. Steam turbines and generators in the 20 to 30MW range are completely assembled on separate beds at Fuji Electric's Kawasaki Factory before shipment, to minimize the on-site installation work. For smaller units, it is possible to assemble both the turbine and the generator on one common bed. However a skid mounted configuration is impossible for larger units like the ones currently being manufactured for the Philippines and Indonesia due to transportation restrictions, Fuji's design aims to reduce the number of assembled blocks in the shipment in order to shorten the installation period. Since most geothermal sites are in remote mountainous areas, and the majority of available labor cannot always be expected to be well experienced, reducing the number of blocks in the shipment becomes even more important from the point of view of both the site schedule management and the

Table 1 Capacity of worldwide geothermal power plants

Countries	Capacity (MW)	
	Year 1990	Year 1995
* USA	2,774.6	2,816.7
* Philippines	891	1,227
Mexico	700	755
Italy	545	631.7
* Japan	214.6	413.7
* Indonesia	144.8	309.8
* New Zealand	283.2	286
* El Salvador	96	105
Costa Rica	0	55
* Iceland	44.6	49.4
Kenya	45	45
Nicaragua	35	35
* China	19.2	28.8
Turkey	20.6	20.6
Russia	11	11
Portugal	3	5
France	4.2	4.2
Argentine	0.7	0.7
Thailand	0.3	0.3
Australia	0	0.2
Total	5,831.7	6,798.0

Note : Fuji Electric supplied geothermal power plants to those countries marked with an *. Year 1995 is as of January.

preservation of reliability.

Geothermal steam contains hydrogen sulphide, and internal stress of turbine parts such as blades and rotor should be within the appropriate limit values for each material to avoid cracking due to stress and corrosion. The maximum centrifugal force is exerted at the base of the low pressure blade in the last stage. For this reason the length of the stainless steel blade of the last stage is limited to 26 inches at 60Hz (nominal) or 30 inches at 50Hz. However, since the enthalpy of geothermal steam is low, the turbine exhaust loss cannot be ignored as a portion of the heat drop across the turbine. By using longer last stage blades, it is attainable to lower costs by reducing the exhaust loss or to make possible a single flow design rather than a dual flow design for the same steam flow. The last stage blades longer than current limit must be made of titanium which is lighter than stainless steel and has excellent anti erosion and corrosion characteristics. Fuji Electric has successfully tested long titanium blades and is prepared to take orders for turbines which use such blades. The physical dimensions of turbines will inevitably increase as longer blades are employed. While contrary to the concept of above mentioned skid mounted design, this technology may be used in the near future for a very big geothermal field if enough steam to support multiple 100MW class units is confirmed.

Most geothermal power generation is in the form of a flash cycle that introduces steam, either naturally dry or separated from geothermal brine, directly into steam turbine. To use low temperature hot water resources for power generation, binary cycle technology employs a suitable thermal medium as the working fluid according to the hot water temperature. This technology has been utilized mainly in the USA. The capacity of a single binary unit is limited from a few hundred kW to 4MW maximum. To build a large capacity plant such as a 40MW plant in the USA, many small units are combined. In Japan the NEDO (New Energy and Industrial Technology Development Organization) is involved in the development of a geothermal binary power plant. There is a problem in that a group of fluorine compounds which were often used as a working fluid cannot be used anymore because they destroy the ozone layer. The application of a hydrocarbon or ammonium solution, or finding new thermal media is very important for further development of binary cycle power plants. Since medium and low temperature resources are more common than high temperature resources, it is possible that the binary cycle power plant will become popular in Japan once its reliability and economical feasibility are proven.

Other technologies that utilize medium and low temperature geothermal resources for power generation are the total flow turbine and the low pressure flash cycle. Fuji Electric designed and manufactured a small scale total flow turbine and carried out a series of factory tests and a site test of approx. 1,000 hours using a geothermal fluid. A possible application of the total flow turbine is to utilize hot water from the separator for power generation, before the hot water is reinjected to compensate for plant parasitic loads.

The low pressure flash cycle is similar to an open cycle OTEC (Ocean Thermal Energy Conversion). It simply generates low pressure steam by flashing hot water, and leads that steam into the steam turbine. It is not necessary to develop new technology because the turbine is an application of the low pressure part of the existing dual flash steam turbine. The characteristic features of this system are that no special working fluid is necessary and that the plant parasitic load is small compared to a binary cycle.

There have been several proposals to use heat from magma or volcanos directly for power generation, and some basic research has been carried out. The Hot Dry Rock technology is probably the most advanced new technologies under development for geothermal power generation. In Japan both the NEDO and the CRIEPI are working on HDR projects and have succeeded in retrieving injected water as steam. The next step will be the improvement of the percentage and temperature of retrieval. An HDR power plant must be a closed cycle so that the flow of injected water can be reduced. (Otherwise a big water dam must be constructed to support even a medium size power plant.) One possibility to solve this problem is to employ a dry type cooling tower instead of the commonly used wet type. The application of a binary power plant is another possibility.

4. Conclusion

This year, the total installed capacity of geothermal power generation in Japan has exceeded 500MW, and will be about 600MW by year 2000. In the Philippines where the increase of the capacity during 5 years between 1990 and 1995 is more than 300MW, construction work of geothermal power plants in Leyte and Mindanao is still going on. In the countries in Central America such as El Salvador and Costa Rica, several new geothermal projects of 50 to 60MW size each have been announced or already contructed for the completion in 1997 or 1998. Indonesia now is probably the country which has most aggressive plan for the development of geothermal energy to generate power. The total of signed BOT/BOO (Build, Operate and Own) contracts exceeds 2,000MW and some of those have been set to work. Besides these big projects, installations of small wellhead units in remote communities which will allow more people to access to electricity are another possibility in a country like Indonesia.

How to deal with the continuously increasing demand for energy while striving for harmony with the global environment is a serious problem for the entire world.

Geothermal power generation, however small a portion in the total, can be a major source of power in the region or in the community where the geothermal resources exist. Fuji Electric, through the construction of geothermal power plants based upon its many experiences worldwide and new technologies, will contribute to solve the global energy problem.