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CASE HISTORIES OF SMALL SCALE GEOTHERMAL POWER PLANTS

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1. ABSTRACT

A large number of rural and remote areas have local geothermal resource areas capable of supporting electrical power generation. Indeed the recent report by the GEA (Gawell et all, 1999) indicates that as many as 39 countries have geothermal resources capable of supplying 100% of these countries needs. Though these geothermal areas may not be connected to the national power grids, with local small-scale geothermal power generation neighboring communities can enjoy the benefits of cost effective and sustainable electricity supply. The current interest in small-scale geothermal power plants for rural local generation and off grid power warrants examining case histories of such small power plants in terms of technology, economic and infrastructure issues.

The cases considered herein are: *(a) Tad's Enterprises, Nevada USA, with 2 modules rated at 1.75 MW total; (b) Empire Geothermal, Nevada USA, with 4 modules rated at 4.8 MW total; (c) EGAT Fang Geothermal, Thailand, with one module rated at 300 kW; (d) NAGQU geothermal, Tibet PRC, with one module rated at 1.3 MW and (e) São Miguel Geothermal No.1, Azores, Portugal, with 2 modules rated at 5.5 MW total, and subsequent expansion to 14 MW.*

In this presentation we have considered the economic, operational and geothermal resource issues. The conclusions are that: (a) small geothermal power projects are technically and economically feasible, with power plant and well utilization technologies that are proven, (b) power costs are acceptable, and (c) most of the problems in developing and operating more such plants relate to availability of financing and maintenance infrastructure.

2. BACKGROUND:

Over 200 ORMAT® Energy Converter (OEC) power modules have been installed, ranging in size from 0.3 MW to 6.5 MW, either singly as small power plants or in combination as larger power plants, with an aggregate total of over 600 MW. These binary based power plant modules operate with geothermal fluids at temperatures of 95°C to 315°C.

For low temperature fluids from 95°C to 175°C, the modular Organic Rankine Cycle (ORC) binary technology, shown schematically in Figure 1, is the most appropriate. In this technology the heat from the flow of the geothermal fluid is transferred to the organic working fluid in a heat exchanger. The working fluid is vaporized and the vapors drive the turbine and the generator. These field proven power units are simple to install and operate, and have near zero environmental impacts. (Elovic 1994)

With two phase geothermal steam/brine flow, a binary ORC configuration, which utilizes all the geothermal energy is employed, as shown schematically in Figure 2. In this case the low pressure wet steam is condensed in the vaporizer of the binary ORC system with the brine is used to preheat the working fluid. Again this small scale power conversion technology is field proven.

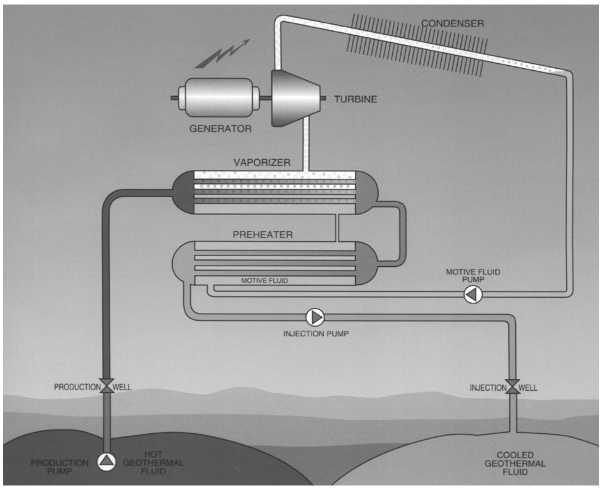

Figure 1. Process Diagram: Air Cooled Binary Geothermal Power Plant

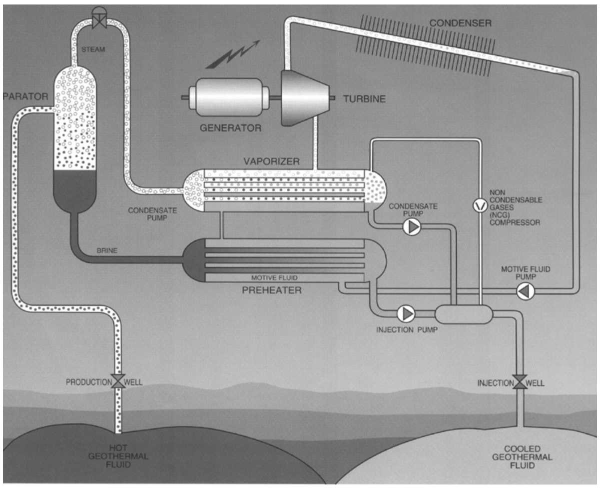

Figure 2. Process Diagram: Two-Phase Binary Geothermal Power Plant

For high temperature resources, from 175° to 315°, other than pure dry steam, the ORMAT® Combined Cycle shown in Figure 3 is employed. This process uses a back pressure turbine with the high pressure steam. The wet low pressure steam is condensed in the vaporizer of a binary system ORC, and the brine is used in the process to preheat the organic working fluid. An example of the very successful application of this process is the Puna Geothermal Plant in Hawaii, where ten 3 MW combined cycle modules have been providing 30 MW of continuous base load power since 1992, (See Figure 4). Another example is the Rotokawa Geothermal Project in the Taupo area in the North Island of New Zealand. This area is a vulnerable situation with a single 33kv connection to the national grid supplying a 38MW load. The geothermal plant produces 24 MW from a Combined Cycle system consisting of a 14 MW steam turbine followed by two 4 MW binary units, which condense the low pressure steam, and a single 5 MW binary unit operating from the hot brine.

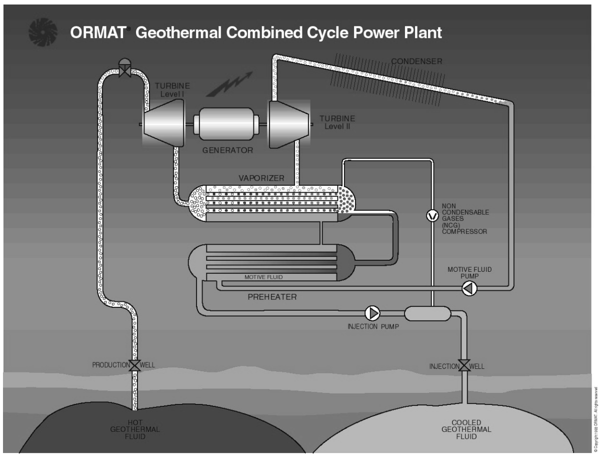

Figure 3. Process Diagram: ORMAT® Combined Cycle Unit

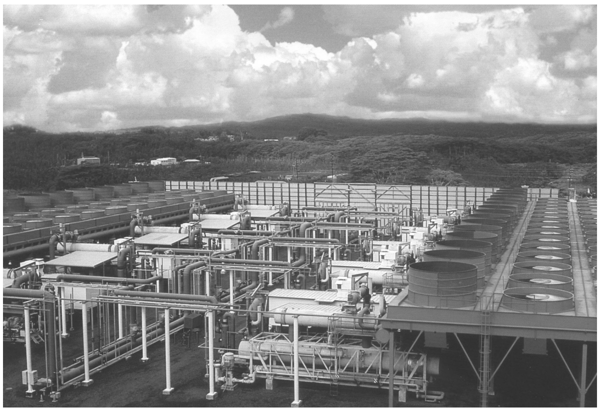

Figure 4. Puna Geothermal 30 MW Air Cooled, Combined Cycle Power Plant

3. CASE HISTORIES

3.1 TAD's Geothermal Plant, Wabuska, Nevada, USA

The Wabuska, geothermal resource is located some 100 kilometers southeast of the City of Reno, and produces up to 3,600 liters per minute of hot water at a temperature of 104°C from two pumped wells. The geothermal fluid was originally produced for agricultural processing but has been utilized for power production since 1984. The power plant, which is comprised of two binary OEC modular power units, is rated at 1,750 kW generator capacity. The plant uses water cooled condensers, with a cooling pond.

OEC modular power unit No.1, rated at 750 kW output and shown in Figure 5, was installed and started into operation in 1984, and power unit No.2, rated at 1,000 kW output was installed and started into operation in 1987. The units operate automatically, mostly unattended, with maintenance and operation provided by a two person staff. The project was privately financed and is owned by Tad's Enterprises, (of Nevada). Output power is purchased by Sierra Pacific Power Company, at a power price in the range of $0.06/kWh, under a 30 year power purchase agreement (PPA) signed in 1985.

The project experienced minor outages from 1985 through 1990. During very cold weather in 1990 several power tripped outages during unmanned periods resulted in freezing in the condensers and pumps. The plant was repaired and operated commercially until 1996. From 1996 the plant was shutdown due to the unavailability of Freon 114, which then was the working fluid. The plant was converted to Iso-Pentane as the working fluid in early 1998 and is currently operating profitably, at level of 1,250kW.

This case demonstrates how a privately financed small power plant, with careful maintenance and operating procedures to assure reliable and economically viable operation, can be operated profitably by its owners

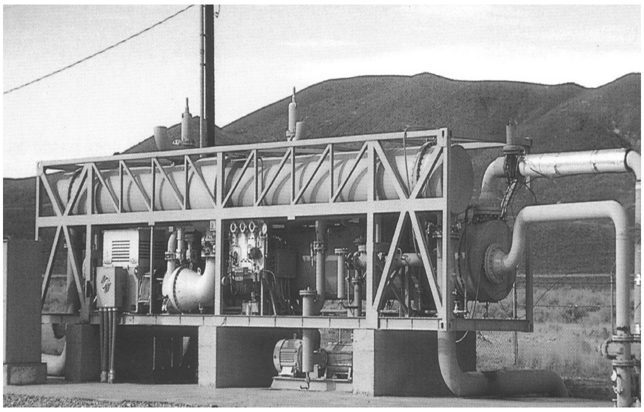

Figure 5. Tad's Geothermal 1.75 MW Water Cooled Binary Power Plant

3.2 EMPIRE L.P. Geothermal Power Plant, Empire Nevada, USA

The Empire geothermal resource is located 100 kilometers north of the City of Reno, and currently produces geothermal fluid at 150°C to supply energy to the power plant and process heat to a nearby agricultural processing facility. The power plant is comprised of four (4) 1.2 MW binary OEC modular power units. The plant uses water cooled condensers with an originally installed cooling pond, which was adversely affected by local wind conditions and later supplemented with cooling towers. The plant was placed in operation as an independent power project in late 1987, to supply up to 3.6 MW to Sierra Pacific Power Company under a long term PPA.

The power plant geothermal fluid temperature, which was 137°C in 1987, dropped to 118°C, average of two wells, by 1989 due to injection cooling. Subsequently both the power plant and the agricultural processing facilities were acquired by Empire L.P., and the geothermal resource management was unified. A program of partial surface discharge was instituted to create a wildlife wetland and the injection configuration was modified. By 1997 additional geothermal fluid at 150°C was introduced into the plant supply and a three cell cooling tower was added. The cooler production wells were shut in. The power plant, as shown in Figure 6, is currently operating at 3.85 MW, some 7% above its design output capacity, and the agricultural processing plant operates at full capacity.

This case clearly demonstrates that with site specific design criteria and prudent unified resource and plant management, reliable cost effective operation of a small scale power plant may be achieved.

Figure 6. Empire Geothermal 4.8 MW Water Cooled Binary Power Plant

3.3 Fang Geothermal Power Plant, Thailand

The Fang geothermal resource, located in a rural agricultural setting near Chang Mai in north central Thailand, utilizes three free flowing wells producing approximately 500 liters/minute of hot water at 116°C. One binary OEC module, rated at 300 kW was installed in 1989 (See Figure 7). The OEC condenser is water cooled by a once through flow of river water. The project produces between 150 and 250 kW, with seasonal variations, with excess heat used for cold storage, crop drying and a spa. (Forte 1989)

The Fang plant also makes use of battery storage to reduce on-peak electric demand by storing electricity during the off-peak periods. In 1996 a Battery Energy Storage Station was set up at Fang with a capacity of 200kVA/800kWh. This system has been operating since 1997 with local and remote control and a 94% efficiency.

The Plant, the only operating geothermal power plant in Thailand, was self financed and is owned and operated by the Electrical Generating Authority of Thailand (EGAT). It has been in continuous operation since 1989. It has excellent scheduled maintenance, including cleaning of well scaling. Overall plant availability is 94%, and EGAT estimates that the cost of the electricity produced is between US$0.063 and $0.086.

This case demonstrates that a very small power plant may be operated to produce reliable and cost effective electrical power, if it is owned and operated by an experienced and well motivated infrastructure agency.

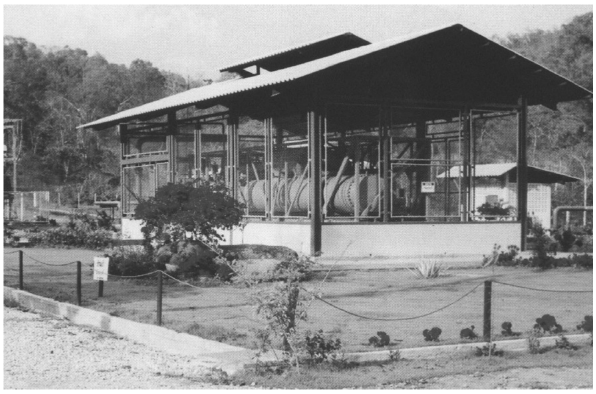

Figure 7. Fang Geothermal 300 kW Water Cooled Binary Power Plant

3.4 Nagqu Geothermal Power Plant, Tibet, PRC

The Nagqu geothermal power plant, which is located approximately 200 kilometers north of Lhasa, is the highest geothermal plant in the world at 4,500 meters ASL. This plant is also the only completely stand alone, off grid geothermal power project. The project was funded by the UNDP and is owned and operated by the Nagqu Power Bureau. It consists of two production wells, and one 1.3 MW air cooled OEC binary modular power plant, installed and commissioned in 1993 (see Figure 8). The wells are pumped and produce 4,200 liters per minute of geothermal fluid at 110°C.

The plant initially operated for 6,400 hours and was shut down following failures of the down-hole pumps. A cable failure occurred after 15 days and a pump seal failed after 7 months of operation. The wells were then operated without the pumps and subsequent severe scaling resulted in the plant being shut down. The down hole pumps were subsequently replaced and the plant was re-commissioned in August 1998. It is currently operating properly.

This case demonstrates that continuous reliable operation can be achieved with small scale power plants, even in very remote areas, if proper maintenance support is provided. There is no doubt that the Nagqu geothermal provides more cost effective power than the small diesel generators, which it replaced.

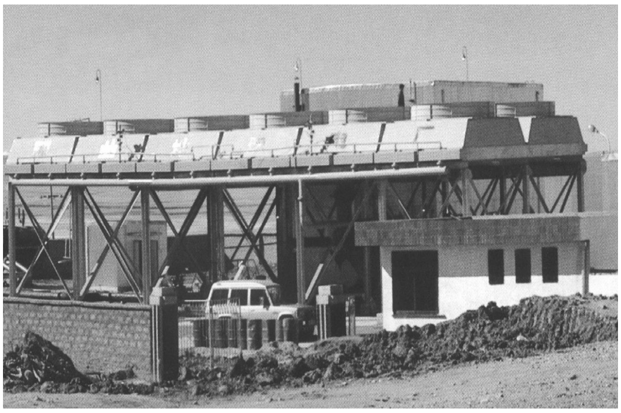

Figure 8. Nagqu 1.3 MW Air Cooled Binary Power Plant

3.5 São Miguel No. 1, Geothermal Plant, Azores, Portugal

The locally financed and privately owned São Miguel No. 1 power plant, consisting of two dual air cooled OEC units, (see Figure 9), commissioned in 1994, generates approximately 5 MW which is sold to Electricity of the Azores, Ltd. The project utilizes two free flowing production wells providing 52 t/h of 4.5 bara steam and 180 t/h of 149°C geothermal fluid. The two phase flow is used in a modular binary system, which also makes use of the steam condensate to dilute the injected brine so as to lower the injection temperature and thus extract more heat from the produced geothermal fluids.

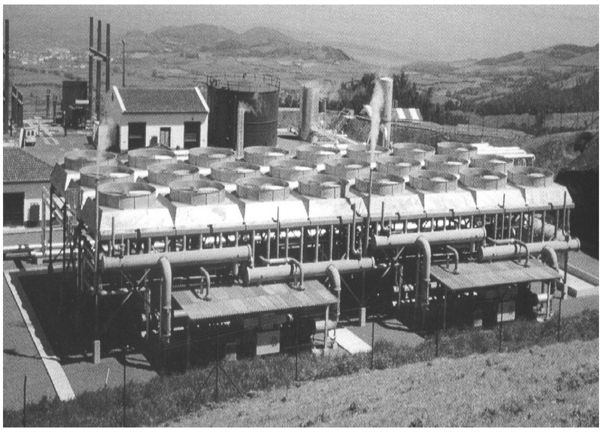

Figure 9. Sao Miguel No.1, 5 MW Air Cooled Two Phase Geothermal Power Plant

The plant has operated continuously, producing a significant portion of São Miguel's base load power, with an availability factor of 98%. Air cooling and 100% injection of all geothermal fluids and gases has resulted in a near zero environmental impact. With the development of additional production wells the construction of the second 9 MW phase was completed in late 1998. (See Figure 10). (Elovic 1994)

This case demonstrates how an island community can incrementally develop and successfully own and economically operate a utility grade base load plant which provides clean power to an environmentally pure region.

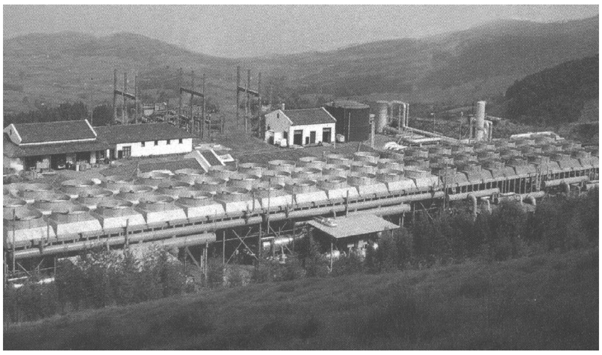

Figure 10. Sao Miguel No. 2, 14MW Total Air Cooled Two Phase Geothermal Power Plant

5. CONCLUSIONS:

Small scale and off-grid power projects are technically and economically feasible. Power plant technologies and well field drilling, production and utilization technologies are proven.

Project owners find the costs of power production commercially acceptable. Operational issues relating to infrastructure, reservoir management, well field facility maintenance and power plant maintenance must be properly addressed.

The success of these small scale geothermal power projects is largely due to the involvement of local interested parties and agencies as active participants in the development, financing, ownership and operation of the projects.

6. REFERENCES:

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