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Small Scale Geothermal Projects for Island Operation

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ABSTRACT

The correlation between volcanic islands and the existence of available geothermal energy has been known for a long time. In big islands like New Zealand, Iceland, Philippines, Japan and others, geothermal power plants for electricity generation are in operation and contribute significantly to the electrical grid, as they do on the mainland.

The development of geothermal power plants in small and medium size islands raises design requirements and issues that are not common to plants on the mainland or big islands. This includes control problems resulting from the size of the electrical grid, changes in the load, transportation difficulties, operation problems and more. Specially designed modular type binary plants can address and solve most of the islands' challenges and supply reliable and low cost electrical energy which can compete successfully with other alternatives such as diesel engine or gas turbine plants.

This paper will illustrate the geothermal modular plant solution for island operation using two power plants that have been built on the big island of Hawaii and in Sao Miguel in the Azores islands as test cases.

1. INTRODUCTION

There are thousands of small and medium size volcanic islands worldwide. The Indonesian archipelago alone consists of more than ten thousand islands – many of which are a result of volcanic activity, with proven geothermal energy resources on many of them and a high probability of finding geothermal energy on many others. This is the situation also in several of the Philippine islands, the Caribbean islands, the islands of Hawaii, Azores and many others. Geothermal exploration and exploitation activity have been performed in some of the above mentioned islands at various stages, and in some power generation power plants have been installed. The combination of complicated and costly conventional power generation on the one hand, and the existence of free geothermal energy on the other, makes the geothermal option very attractive from the operational and economical points of view. The development of geothermal power generation on small islands is supported in many cases by the government and by international organizations as part of rural electrification plants. In Indonesia for example, there is a presidential decree that gives the State Electricity Corporation (PLN) authority to develop small scale power plants of less than 10 MW in size. This development includes both the resource development and power plants.

2. THE CHARACTERISTIC OF AN ISLAND ELECTRICAL SYSTEM

There are several factors that are typical to an electrical system on the small to medium size island.

Size of the electrical network – the island electricity demand can vary from a low number of MWatts on a small island to several tens of MWatts on a medium size island.

Changes in load – the variations between peak load and off peak load are much higher than on the mainland. The electrical generation system has to adjust itself to large and rapid changes in load. The control of a single power generator has to be very accurate, since it cannot rely on a very strong national grid.

The generating equipment shall be simple, with high availability and reliability. The manpower for operation and maintenance on the island is limited and the technical support infrastructure in many cases is poor. In most of the cases any technical support and spare parts must be transported from the mainland. A failure of one generating unit may strongly impact the whole grid.

Environmental issues – many of the islands are based on tourism and are very sensitive to pollution and noise. The generating equipment cannot be installed in a remote location, due to the size of the island, so has to be environmentally friendly and at low visible height.

The port, in many cases, is limited in size and in lifting equipment capacity. The power plant equipment cannot be of high weight and size.

3. THE DIESEL GENERATOR OPTION

Electricity generation today on the small and medium islands is mainly by the means of diesel generators. The electricity demand is usually too small for a coal-fired or a combined cycle-type power plant, so the diesel generator is the preferred option. The cost of electricity produced by a diesel generator is high due to the cost of the fuel, which has high cost components of transportation and the cost of operation and maintenance. A typical electricity price for this type of power generator is above US $0.20 per kWh. This price was much higher during 2008, when the price of crude oil reached record levels of US $150 per barrel, and may be increased again as a function of the changing price of oil.

The diesel option is non-environmentally friendly, and the gas pollution levels and noise levels of such a plant are high. The option of using natural gas for power generation on a small island does not exist, so the fuel in most of the cases is heavy fuel oil and in most places the regulations require the installation of expensive gas scrubbers.

4. THE GEOTHERMAL OPTION

In islands where geothermal energy is available a large portion of the electricity can be generated by modular energy converter units which utilize the geothermal fluids as the heat source. Such units, although higher in initial capital cost compared to diesel engines, are much more cost effective in the long run, as they eliminate the need to transport fuel to the island and availability is much higher than diesel engines. The life time of geothermal modular units is more than 25 years and maintenance requirements are much lower than that of diesel. Frequent major overhauls with replacements of a large number of components, which are a major expense in a diesel plant, are almost non-existent in a modular geothermal plant. The geothermal fluid, after passing through the geothermal unit, is reinjected back into the ground and the environmental impact is minimal compared to the CO_2, NOx, SOx and other gas pollution of a diesel engine.

Two basic concepts are the candidates for geothermal utilization in an island, the flash steam and the binary concept. The steam flash units are very popular for large size plant where a condensing type turbine is used. For small size installations a back pressure type steam turbine is used in some places. The back pressure steam turbine plants are low in initial investment but their thermal efficiency is low and their environmental impact is high since the low pressure steam is directly released to the atmosphere.

In this paper we will describe the binary type modular geothermal units which are preferred for small size island units.

Three types of modular geothermal units, based on the organic Rankine cycle (ORC) binary concept, are available for low, medium and high enthalpy geothermal resources.

4.1 Low Enthalpy

The low enthalpy unit utilizes brine as the heat source. The brine is usually pumped from the well with down-hole pump, as in the projects in Steamboat, Nevada and Ormesa, California. In other cases the brine, mixed with small portion of steam, flows freely from the well without the aid of a pump. Figure 1 is a picture of a low enthalpy unit which has been working in Wabuska, Nevada for more than 25 years. Such a unit is installed in an ISO container shape after being assembled and tested at the manufacturing plant. The shipment to the project site is simple and the field installation time is minimal. Since no steam and no gas are involved in the process the entire heat source fluid is reinjected and there is zero pollution to the atmosphere. The units are air cooled or water cooled as a function of the ambient conditions and availability of water.

Figure 1: Wabuska binary unit

4.2 Medium Enthalpy

The medium enthalpy unit is also a skid mounted module shipped in several packages for easy site installation. The heat source of this type of units consists of steam and brine coming out of a separator. A typical medium enthalpy unit is the unit installed on the island of San Miguel in the Azores archipelago. The unit makes use of the two-phase binary cycle and accepts steam at around 5 bara and brine at 150ºC from a separator as heat source. The steam enters the vaporizer of the binary unit for the boiling process and the brine is mixed with the steam condensate and enters the preheater where the organic fluid is heated before entering the vaporizer. Figure 2 is a picture of the Azores Island's phase 1 and 2 units, and Figure 3 is a process flow diagram of the two-phase binary cycle. A more detailed description of the Azores project will be presented in the next sections.

Figure 2: Azores project, stages 2 and 3

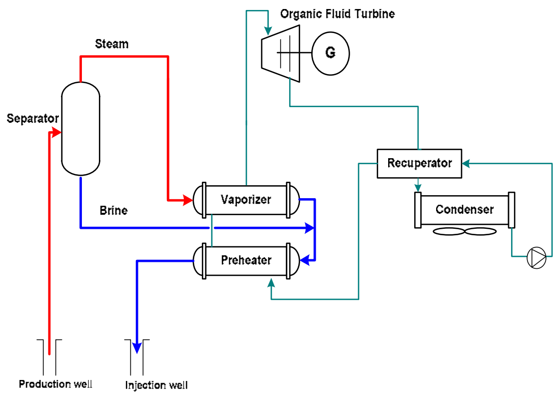

Figure 3: Two-phase binary process flow diagram

4.3 High Enthalpy

A modular-type unit for utilizing high enthalpy geothermal resources is demonstrated by the Puna project located on the Big Island in Hawaii. The unit is based on the geothermal combined cycle (GCCU), where high pressure steam, after separation, enters a back pressure-type steam turbine and after expansion the low pressure steam is used as the heat source for an ORC-type unit. The high enthalpy unit, like the others, consists of pre-assembled and tested modules consisting of the back pressure steam turbine and binary turbo-generator skid, heat exchangers skid and a power and control shelter.

The GCCU make use of a simple back pressure steam turbine with relatively low blades compared to the last stages of a condensing steam turbine. The moisture content in the last stages is low and the condensing of the steam is done at above atmospheric pressure, eliminating the need for complicated vacuum systems. NC gases can be purged from the steam condenser either to the atmosphere or to an abatement or injection system.

The Hawaii project is a described in more detail later. Figure 4 is a picture of the Puna project and Figure 5 is the process flow diagram.

Figure 4: Puna project, general view

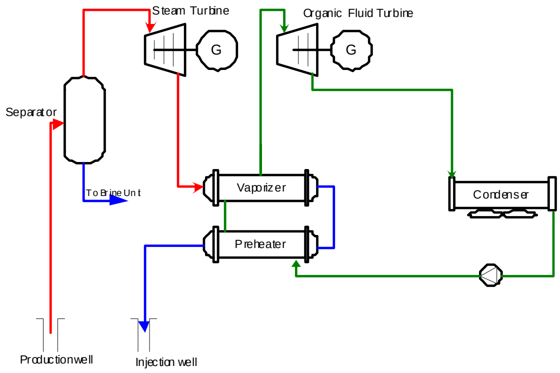

Figure 5: GCCU process flow diagram

5. CASE STUDIES

5.1 The Azores Island Case

The island of Sao Miguel is in the Azores archipelago, located in the Atlantic Ocean. The population of the island is about 140,000 and its economy is based on agriculture and tourism. Geothermal electricity generation started in 1979 when the first well of the Pico Vermelho field was drilled and has been developed in stages. The first stage was a small power plant in the Pico Vermelho field consisting of a 3000 kW back pressure steam turbine The plant generated only 600 kW due to lack of geothermal fluid from the drilled wells. This stage 1 plant was disassembled and removed later when the new Pico Vermelho plant was installed The second stage was a 5.08 MW (gross) modular binary plant at the Ribeira Grande site, followed by the third stage of another modular binary plant of 9.4 MW (gross) at the same location. The fourth stage was completed in 2005 when the Pico Vermelho 10 MW (net) plant started commercial operation.

Today geothermal power generation supplies around 40% of the island's demand and is used as a base load generator with diesel generator units taking care of the changing loads between the peak load of around 80 MW in the evening hours and off-peak load of around 40 MW in the early morning hours. (The numbers relate to 2008). The power units of the plants are modular two-phase units with a size of 2.5 MW at the Ribeira Grande stage 1, and up to 12.6 MW at the new Pico Vermelho plant. All the Sao Miguel units were designed and built for island service, with construction and control features accordingly.

The geothermal plants are operated with daily coordination with the grid control center (dispatch). Although most of the variable loads are handled by diesel generators, from time to time the dispatcher instructs shut down of one or two geothermal units, per load requirements of the grid.

The following is the technical data of the Pico Vermelho plant:

PICO VERMELHO - TECHNICAL DATA

Steam flow:	74.86 t/h
Brine flow:	346.7 t/h
Steam pressure at inlet to plant:	5 bar a
Brine temperature at inlet to plant:	161.3°C
NCG in steam:	1.8% (by weight)
Design ambient temperature:	22°C
Gross power at design point:	11,450 kW
Gross power at 13°C ambient temperature:	12,600 kW
Net power at design point:	10,000 kW

5.2 The Puna Case

The Puna project is located on the Island of Hawaii (the Big Island) in the Hawaii archipelago. About 150,000 inhabitants live on the island, plus an average of about 20,000 tourists. The main tourist attraction is the active volcano and national park of Kilauea. The Puna project is located not far from the volcano and the high pressure steam heat source originates from the volcanic geothermal system.

The utilization of the heat source is achieved with 10 modular geothermal combined cycle type 3.3 MW units. The high pressure steam at around 16 bar enters a back pressure type steam turbine, expanding to around 1.5 bar and generating 1.6 MW. The low pressure steam proceeds to an ORC type unit where another 1.7 MW is generated. The steam turbine and the organic fluid turbine are connected to a common synchronous generator and are assembled together with a reducing gear of the steam turbine on a common skid. Ten identical modules are assembled side by side for a 33 MW gross power plant. The selection of the geothermal combined cycle concept was made in order to have a simple unit where the high pressure steam expands to above atmospheric pressure, thus eliminating high moisture content in the last stages of the turbine, and the condensing of the steam is done without the need for a vacuum system. The non condensable gases containing CO_2 and H_2S are vented from the steam condenser and compressed into the condensate stream on its way to the injection wells. The result is zero pollution of liquid and gas from the plant. The Puna project is in operation from 1993 with a very high availability.

The following is the technical data of the Puna project:

PUNA - TECHNICAL DATA

Plant output power:	33 MW
No. of combined cycle OEC units:	10 each, comprising: - one Level I special turbine - one Level II organic turbine
Cooling media:	Air
Generator output voltage:	3-phase, 13.8 V
Generator RPM:	1800
Power pant output voltage:	93 V
Geothermal fluid: type:	Saturated steam
Temperature:	600°F (315°C)
Pressure:	1430 psia (100 bara)
Inlet pressure into the turbine	232 psia (16 bara)

6. DESIGN FEATURES OF AN ISLAND UNIT

A modular unit for island operation is different from a mainland-type unit in several aspects related to the special conditions and requirements of an island electrical system and island construction and operation conditions.

6.1 Reliability And Availability

Geothermal binary units are usually very reliable and have availability levels of 96% and higher. Units built for island service should be even better, since the whole grid is relatively small and the geothermal unit takes a major portion of the supply. Critical components in the unit are built with a high level of redundancy and with more protection features. On the other hand, the operational range and protection limits are expanded much more compared to a standard unit. The idea is to minimize as much as possible the events of unit trip and shutdown which may cause the entire island grid to collapse. As an example, a standard unit will shut down in cases of over or under frequencies of plus or minus 10%. An island unit should be designed and built to work within a much wider range. An over frequency or under frequency alarm will be activated at the regular settings levels, but the unit will stay in operation. Other design features related to availability are the design spares. In an island power plant the geothermal fluid production capacity of the well field will have up to 20% extra capacity to compensate for cases of well maintenance and field capacity decline. This will prevent reduction in plant generation due to geothermal fluid shortfall. Another design parameter important to the island operation is the design cooling water or ambient air for condenser cooling. The usual selection of the water or air design temperature is the annual average. In an island unit the design may be the summer average temperature in order to assure full capacity generation during summer days.

Design spares may also be taken into consideration in the design pressure of the pressure vessels (mainly heat exchangers) in order to prevent the unit tripping due to high pressure from change in geothermal fluid parameters, or for other reasons.

6.2 Control Features

The island unit is built as a “stand alone” unit with its own speed and voltage control. The voltage and frequency set points, as well as the rate of changes can be changed as a function of the grid requirements and may be controlled by the grid system control (dispatch). In special cases, upon request, the control system can allow remote change of the set points by the dispatcher. The ramp rate of the load in terms of the MW change per minute is higher than in the standard units and may be designed per the island grid requirements. In some cases a special flywheel may be added to the turbo-generator in order to increase the unit rotating inertia and make it less sensitive to sudden load changes. The island unit must be able to work at partial load as a result of change in the island loads or as requested by the grid control center. Figure 6 is a schematic process flow diagram (PFD) of a typical unit. The immediate load and frequency control is done by the controller sending signals to the turbine control valve (1). In case of partial load the unit can go into heat removal mode of operation in which the bypass valve (2) starts to flow part or all of the organic fluid vapor directly into the condenser without passing through the turbine. This way the unit consumes the entire heat coming from the well field, but generating part of the generator capacity and even zero power. This feature allows partial load operation without frequent change in well flow rate and wellhead pressure, which is detrimental to the well’s integrity.

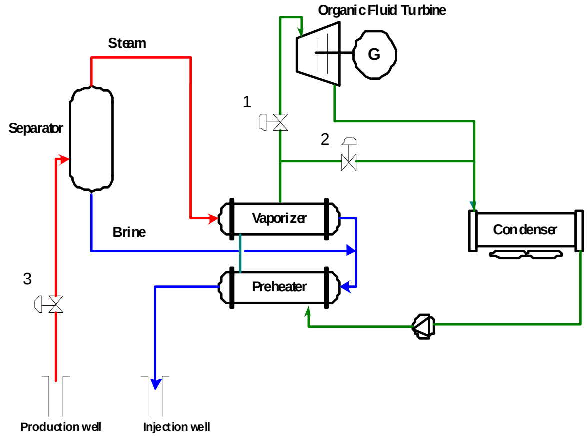

Figure 6: Typical unit process flow diagram

7. CONCLUSIONS

The use of modular geothermal power units on islands where geothermal energy exists can contribute a large portion of the electrical grid requirements. Unlike some other power generation options on the islands, geothermal energy is environmentally friendly and the long term cost of the energy is lower than the alternative means of power generation.

Three types of modules have been presented for geothermal resources of low, medium and high enthalpy, all base on binary type organic Rankine cycle (ORC).

The island type modular power units are designed and built with special features which are the result of the electrical grid operation parameters of the island.

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