Downhole Generator for a Geothermal Injection Well

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Keywords

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ABSTRACT

The Northern California Power Agency (NCPA) has successfully developed and demonstrated a new technology to recover the hydraulic head energy of reinjection water so that additional electricity can be generated from under-pressured reservoir injection. The innovative approach incorporates an off the shelf 400 hp electrical submersible pump into an existing geothermal injection well to produce electricity and reduce plant house power expenses. This Pump As Turbine Project resulted in a sustainable generation of 250 kw.

NCPA applied for and received a California Energy Commission Grant with the objective of modifying one existing off the shelf downhole electrical submersible geothermal pump to operate as a turbine-generator. Modifications to the downhole system include a valve to control flowrates, downhole pressure monitoring capability, and a protective shroud for the pump/motor. A wellhead landing spool allows for power cables to extend from the well without any release of geothermal fluids. An at-grade electrical facility was constructed to interconnect the turbine-generator with the local distribution system and provide generator and system protection. The surface electrical equipment includes transformer, switchgear, cabling, relays, and a medium voltage transmission system. The downhole pump was installed at a depth of 1,800 feet in an injection well and performance is being monitored to develop benchmarks.

The specific economic objectives of the Project will be presented in this paper. Due to the success of this first downhole Turbine, a second downhole turbine has been planned by NCPA. Other design improvements are discussed.

1. Introduction

Established in 1968, the Northern California Power Agency (NCPA) is a California Joint Action Agency. NCPA membership is open to municipalities, rural electric cooperatives, irrigation districts and other publicly owned entities interested in the purchase, aggregation, scheduling and management of electrical energy. NCPA operates two geothermal power plants of nameplate 110 megawatts each at The Geysers geothermal field, located in the Mayacamas mountains of Sonoma and Lake Counties, and the agency also owns and operates the 70 deep production wells that supply these power plants with steam. In addition, the geothermal project includes 8 deep injection wells used to re-supply the geothermal reservoir with water to create additional steam, 10 miles of surface pipelines to deliver the produced steam to the plants, two surface water collection ponds, and a co-owned major

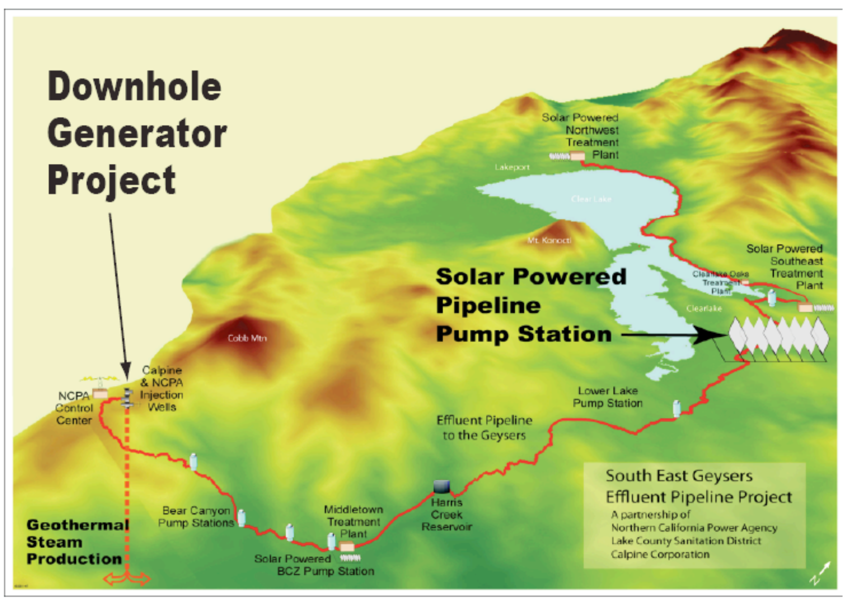

Figure 1. The fuel source for NCPA's geothermal project is the Southeast Geysers Effluent Pipeline Project. The Downhole Generation Project is part of the SEGEP Pipeline and will reduce the horsepower requirement to operate the SEGEP Pipeline.

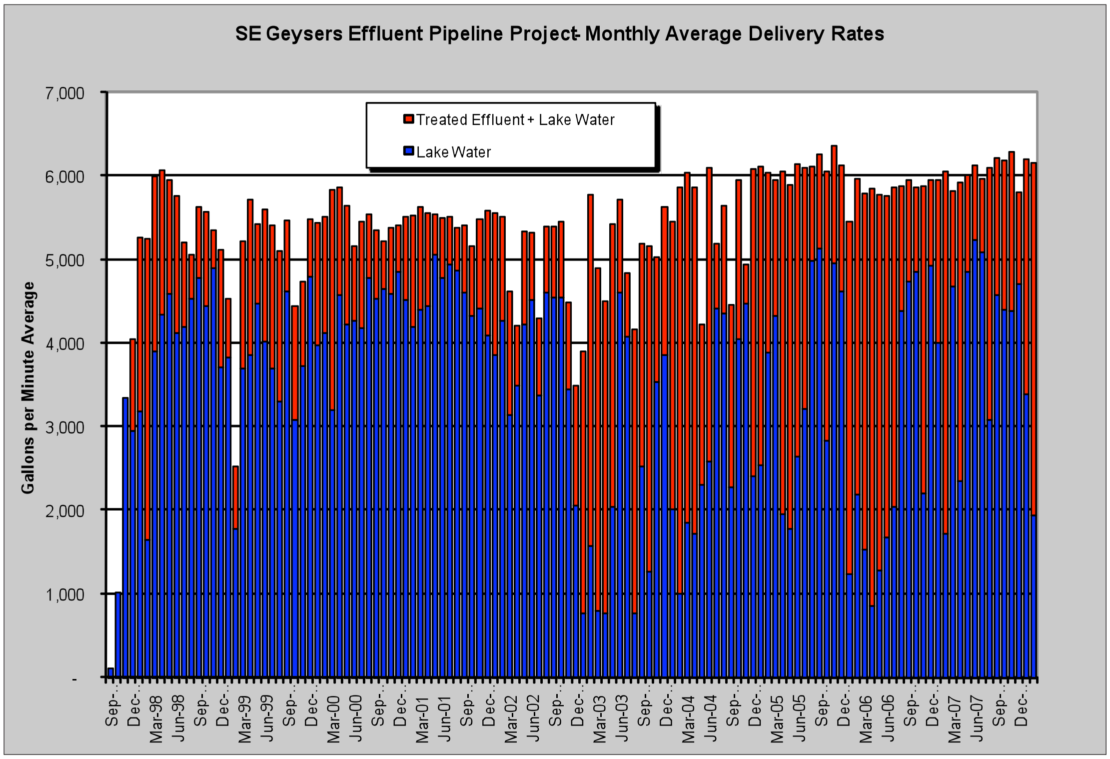

Figure 2. The Southeast Geysers Effluent Pipeline project began water deliveries on September 25 1997. The pipeline operates at an average rate of 6,100 gpm.

2.2 Technical Objectives Accomplished

The specific technical objectives of this project that were accomplished since the April startup:

- Modifed one existing down-hole submersible geothermal pump to operate as a turbine-generator in a geothermal reinjection well.
- Designed and constructed an at-grade electrical facility to interconnect the turbine-generator with the distribution system and provide generator and system protection.
- Installed a down-hole turbine-generator at a depth of 1,800 feet in an injection well and operated it for a continuous period.

wastewater delivery system consisting of five pump stations and 26 miles of underground pipeline that are used to supply additional fluids for injection.

NCPA operates the Southeast Geysers Pipeline project on behalf of itself, Calpine Corporation and LACOSAN. This pipeline has a 30 year plus expected operation life utilizing currently about $1 million a year in electricity for pumping secondarily treated effluent to the Geysers from LACOSAN's facilities. This water is integrally required for the beneficial operation of NCPA's Geysers assets.

2. Project Description

The Downhole generator was installed April 2009 as part of the SEGEP Project. Approximately 1,200 gallons per minute (gpm) is injected into well N-7. Figure 2 shows that the SEGEP operates at more than 6,100 gpm and injectate is a combination of treated effluent and makeup lake water.

2.1 Well Selected for Downhole Generator

Injection well N7 is ideally situated within the steam reservoir for the downhole generator project. It is located in the lower reservoir pressure area of the NCPA field and is completed as a horizontal injection well. Figure 3 is a well schematic of injection well N7. It is the workhorse injector for the NCPA geothermal leasehold and was originally completed in 2003. Therefore the upper casing is still in very good condition. A temperature pressure spinner survey of the well indicated that the well was on a vacuum to almost 4,000 feet. (Figure 4)

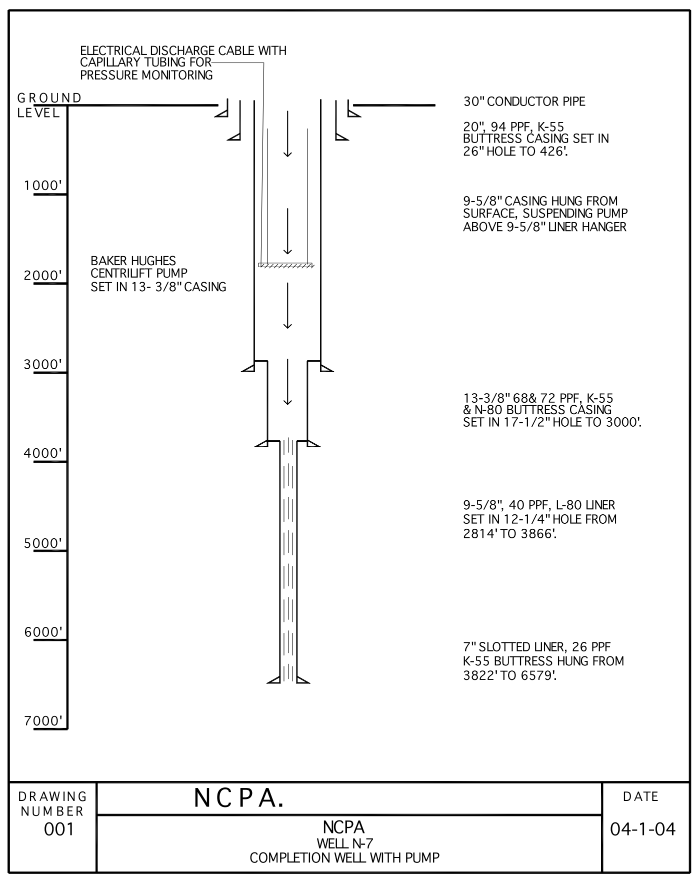

Figure 3. Schematic of Injection Well N7 with the Downhole turbine installation.

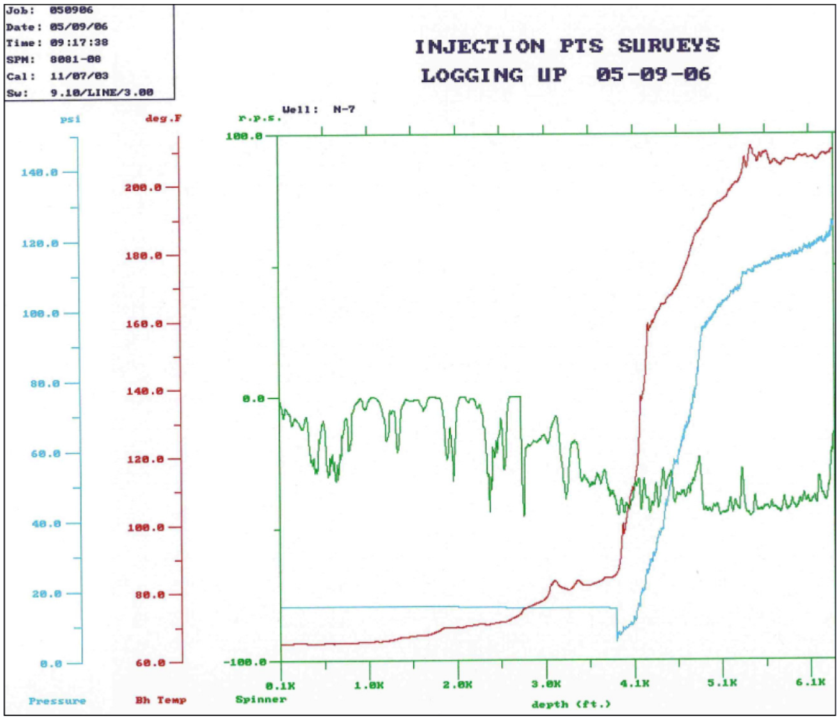

Figure 4. Pressure Temperature and Spinner Survey of Injection of Well N7 prior to the Downhole turbine installation indicating temperature of less than 100 F above 4,000 feet.

- Measured power output and performance of the turbine-generator, i.e. the conversion rates for reinjection water flow and head available versus net electrical output.

2.2.1 Remaining Technical Objectives

- The specific technical objectives of this project that remain to be accomplished:
- Remove the generator, inspect the equipment inside and out to determine that the materials of construction and the component design are compatible with the geothermal environment.
- Document results and report in a manner that can be used by geothermal power plant operators to evaluate the technology and apply it to their reinjection wells.
- In addition to this GRC paper, the project participants will present and publish in other appropriate public venues the project results.

2.2.2 Economic Objectives

A down-hole generator program has the impact of making clean geothermal power more cost effective and increase the life of the field. The reservoir will continue to generate for a far longer number of years with the successful implementation of this project than without.

The specific economic objectives of this project are to:

- Quantify the projected 6-year costs to acquire, install and operate a down-hole geothermal turbine-generator
- Quantify the projected cumulative electrical output during that time under sustained and typical injection conditions.
- Compare the costs of the electricity produced in this manner to California's electricity market, to other renewable generation costs, or to other relevant standards. Determine the Benefit Cost Ratio for the project to assist other operators in calculating the economic suitability. For this analysis, $98 per MWh was assumed as the value of renewable geothermal generation.

Furthermore, the proposed project helps offset some of the overall costs associated with the drilling and development of new injection wells through revenues generated by power generation. Recovering the re-injection water energy in the form of generated electricity will allow the geothermal resource to improve its efficiency and output. An overall increase in efficiency and output increases the competitiveness of geothermal with the other forms of energy.

The project will ultimately result in more electricity being derived from the geothermal resources in California. Use of geothermal resources for electricity generation is more reliable and predictable than oil or natural gas powered plants due to fluctuations in availability, and thus fluctuations in cost. Geothermal resources are renewable and are generally more environmentally friendly than oil and natural gas, due to the potential for spills of petroleum into the environment. Electrical generation from the use of hydrocarbons is also a leading source of air emissions in California. This project will lead to a reduction in air emissions as this technology is essentially non-polluting hydro derived electricity generation.

2.3 Expected Project Benefits

2.3.1 Financial Benefits

The proposal's measurable benefits were calculated by the following financial key performance indicators, assuming that the value of renewable geothermal generator is held at $98 per MWh and the Project life is six years, the Project Capital Cost is $600,000, Operating and Maintenance is $50,000 per year and unit availability is 0.25 MW with an 85% capacity factor:

Table 1. Key Project Economic Indicators.

6 yr NPV of investment @ 5% DR	$564,850
Total Investment	$600,000
6 yr IRR of Investment	36%
Discounted (5%) Benefit/Cost Ratio	1.55
Nominal Payback	3 years

Depending on the type of financing, the Project Owners will experience a payback of three years.

2.3.2 Non-Financial Benefits

The 0.250 MW project will cause the reduction in greenhouse gas emissions of CO2 and NOX in the amounts of 730 tons and 0.8 ton annually, respectively. No Renewable Energy Credits are included in the economic analysis for the project; however, AB 32 and current regulatory actions could add even more tangible value to these reductions, and public relations impact of this activity could be quite favorable, if not financial.

3. System Installation

3.1 Overview

The Re-injection Well Down Hole Power Generation at The Geysers project was designed to take advantage of available head energy from reinjection for additional electricity generation. It is estimated that for only the NCPA lease, if six wells are fitted with the down-hole turbine, then more power will be generated than is used to pump Lake County effluent to The Geysers. (3 MW). For the entire Geysers Field, assuming that only 1/2 of the 43 injection wells utilized during 2003 can be retrofitted with a down-hole turbine, and then more than 7 MW of power would be generated with a successful application of this technology. Because reinjection wells all ready exist and the supply of reinjection water is established, the costs to further develop this technology will only require the capital costs of the down hole and electrical equipment to transfer the power and the associated installation costs.

3.2 System Description

The downhole generator is comprised of three major submersed components; the turbine, generator, and cable. At grade facilities include switchgear and transformer, and control and monitoring equipment. Figure 3 shows schematic overview of a downhole pumping system which is very similar to the generating system.

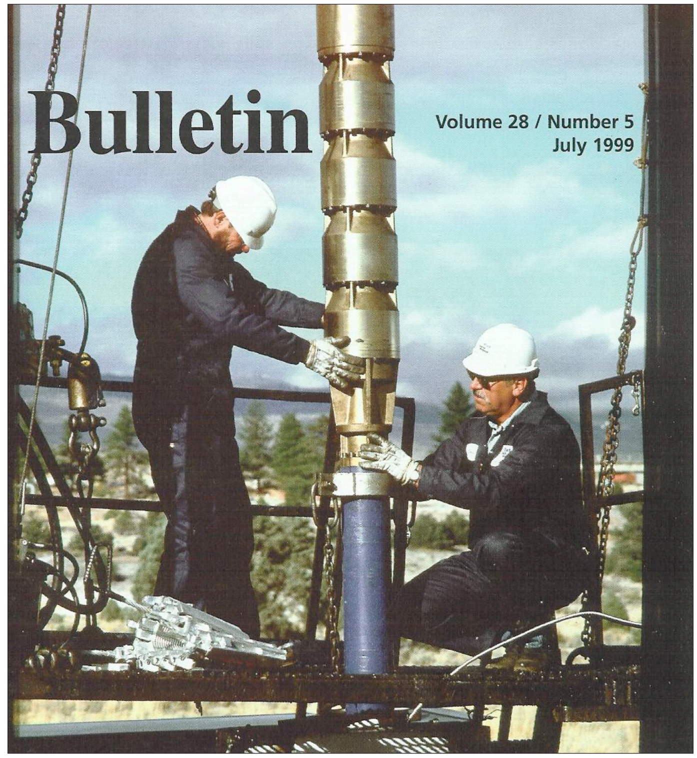

Figure 6. Typical Pump Installation: The technology used to install the downhole generator has been available for at least 20-years in the geothermal industry.

The turbine is a multistage turbine consisting of a rotating impeller and stationary diffuser, as shown in Figure 5-1. The impellers and diffusers are made of corrosion resistant nickel-resist for prolonged life. The generator is a two pole, three-phase, squirrel cage induction generator producing 2,300 VAC as shown in Figure 5-2.

3.3 Pump Installation

The pump was installed with a rig from Boart Longyear. The crew has considerable experience installing geothermal pumps. The installation process took four days. No unexpected problems were experienced.

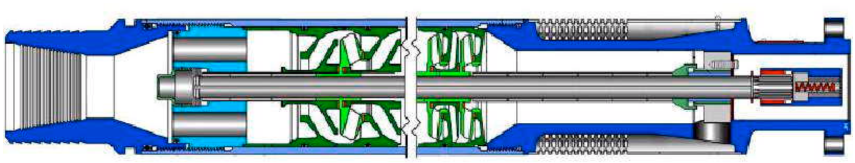

Figure 5-1. Cross section of Turbine Assembly.

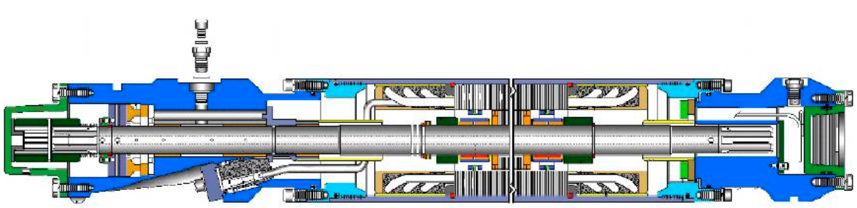

Figure 5-2. Cross section of Generator Assembly.

3.4 Electrical Protection Scheme

PAC / MIS of Berkeley provided the electrical engineering design services for the Project. Shown as Figure 7 is the single line diagram. The switchgear was designed for operation on a 5-kV, three-phase, 3 wire, impedance grounded, 60-hertz system.

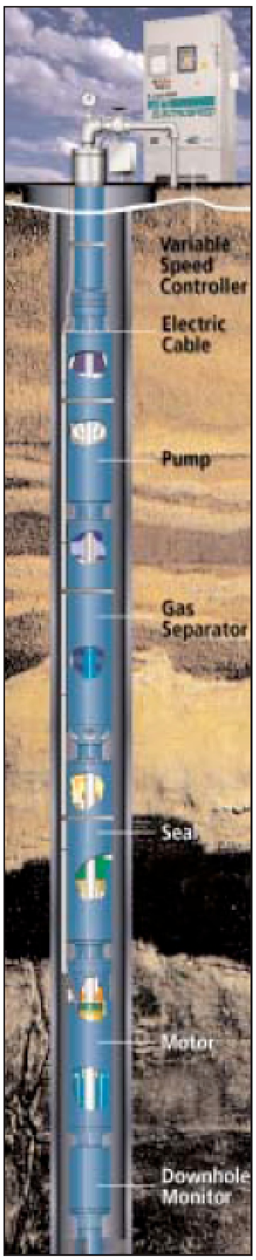

Figure 5. Typical Down Hole Pumping System That Was Installed in Well N7.

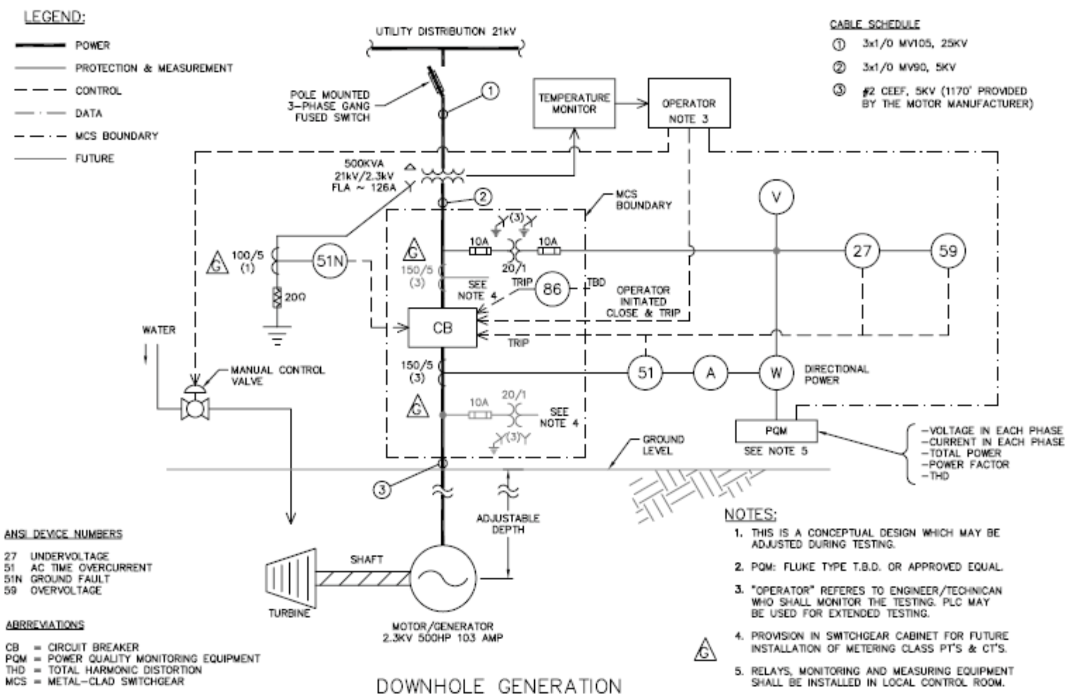

Figure 7. Electrical Protection Scheme as developed by PAC / MIS of Berkeley California.

Table 2. Circuit breaker ratings for the metal clad switchgear.

Maximum Voltage	4.76 kV
BIL Rated	60 kV Peak
Continuous Current (4.16 kV)	1200 Amperes
Short-Circuit Current at rated	Maximum kV
29 kA RMS SYM	
Rated Voltage Range Factor K	1.24
Closing and Latching Capability	97 kA Crest
Maximum symmetrical Interrupting	and Three Second Rating
36 kA RMS SYM	
Nominal 3-Phase MVA Class	
250 MVA	
Rated Interrupting Time	Five cycles

4. Performance

Figure 8 is the relationship between injection rate and generation. Following startup, at flowrates less than 800 gpm, the generator is "motoring" i.e. it is taking electricity. With increasing flowrate, the generator output rapidly increases to a maximum of 250 kw at 1,300 gpm. The generator is limited at this flowrate due to maximum current rating of 100 amps.

5. Conclusion

NCPA's Downhole Generator Project represents a successful extension of the Agency's efforts to utilize its clean, green and sustainable electric generating resources to the fullest. On balance, system costs appear to be on track to more than offset costs and provide a rate of return greater than NCPA's cost of capital. Given the apparent success of the project, NCPA plans to construct a similar project at another location along the SEGEP, further extending its clean, green and sustainable electric resources.

6. Acknowledgements

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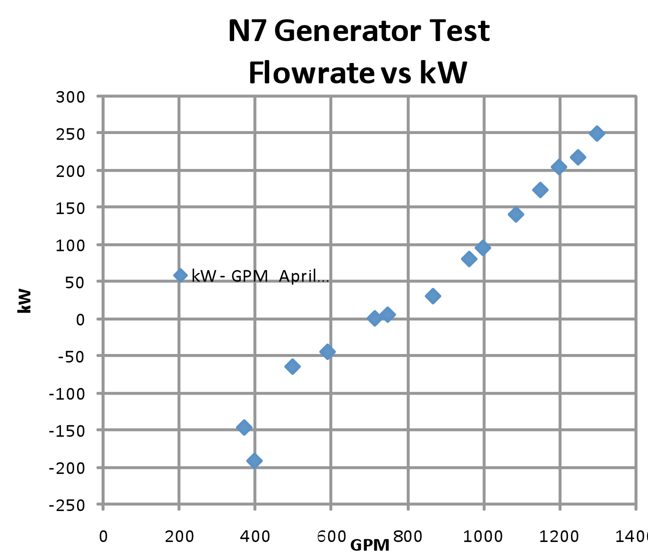

Figure 8. Flowrate vs. kw relationship for the downhole turbine.

7. References

California Energy Commission. Geothermal Target Solicitation, GEO 03-01, Proposal #20.1, Northern California Power Agency, Reinjection well dowhnole power generation at The Geysers.