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The Stillwater Triple Hybrid Power Plant: Integrating Geothermal, Solar Photovoltaic and Solar Thermal Power Generation

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ABSTRACT

The Stillwater geothermal project is located in Nevada, USA, and is owned and operated by Enel Green Power North America, Inc. (EGP-NA). The first phase of the project began with a geothermal plant, a 33 MW gross binary plant which was commissioned in 2009. A desire to increase output led EGP to add 26 MW of solar photovoltaic (PV) power to the project in 2012. The solar PV project size was tailored to complement the geothermal plant output degradation during hot summer temperatures. In 2013, design began on an additional solar project using Concentrated Solar Power (CSP) thermal technology. The augmentation project relies on linear parabolic trough systems to add energy to the incoming geothermal fluid, which allows the binary plant to increase output. The project consists of collectors, a heat exchanger, a circulating pump and a control system integrated with the geothermal plant. The solar field adds about 17 megawatts of thermal energy, and is estimated to add an equivalent of up to 2 megawatts of boost in power generation to the geothermal power plant. The following paper presents the Stillwater resource park as a prime case study for the benefits of collecting multiple renewable energy generation types, which harness multiple resources, such as existing infrastructure, transmission capability and human capital. It serves as a template for similar projects blessed with comparable resources. Performance contributions of the geothermal, solar PV and solar thermal aspects are presented, with commentary on operations and lessons learned for the integrated unit. Stillwater was the first geothermal power plant to be paired with solar photovoltaic generation and is also the first to be coupled with concentrating solar power field on a major utility scale. When completed, it will be the first power plant to incorporate the three renewable technologies.

1. INTRODUCTION

The Stillwater power plant site is located 12 miles (19 km) northwest of Fallon, Nevada in the USA. The site, owned and operated by EGP-NA, is the world's first utility scale, combined geothermal and solar power plant. Total output from the plant is sold to NV Energy.

The Stillwater site is a good case study for augmentation at a geothermal field experiencing usual decline after years of operation. Typical of most geothermal plants, geothermal resource aspects such as temperature, pressure, flow and/or non-condensable gas content may change over time. Common counter measures are to rework the existing production wells or drill replacement wells. However, there is no guarantee of success since reworking a well in a depleting resource zone may not be successful or drilling a new well runs the risk of a dry/unproductive well. Instead of drilling new wells, solar augmentation is a plausible option. The site must meet certain requirements, but it is an option worth considering if a site has a sufficient solar resource.

Building off its earlier success in adding solar photovoltaic to the generation mix at the plant, EGP-NA determined that adding concentrated solar thermal energy to the geothermal brine was a viable option of addressing the resource decline instead of sinking more funds into finding new production wells. EGP-NA had developed the design concept and integration optimization with the existing facility. EGP-NA then approached POWER Engineers, Inc. (POWER) to become the engineer for this new solar thermal project. POWER was the design engineer for the Stillwater geothermal plant and was also involved with the solar PV project.

The geothermal and solar applications at Stillwater presented several technical challenges that are unique and distinctive. Each is discussed in greater detail starting with the original geothermal power plant.

2. GEOTHERMAL

The Great Basin desert of Nevada is a well studied geothermal resource area. In 2007, EGP-NA hired POWER to provide engineering services for initial feasibility and conceptual design studies as well as definition for a binary geothermal plant. After development and conceptual engineering was complete, POWER transitioned to the role of the engineer in the EPC development team with the construction contractor, The Industrial Company.

The geothermal plant, commissioned in 2009, was a custom designed and built geothermal power plant (atypical of the modularized binary geothermal systems used on other projects) to optimize its resource. The 33 MW, four-turbine unit Stillwater plant is un-recuperated, uses the organic Rankine cycle with isobutane as the working fluid and employs air-cooled condensers.

Figure 1 shows the simplified process flow diagram of the original, completed geothermal power plant.

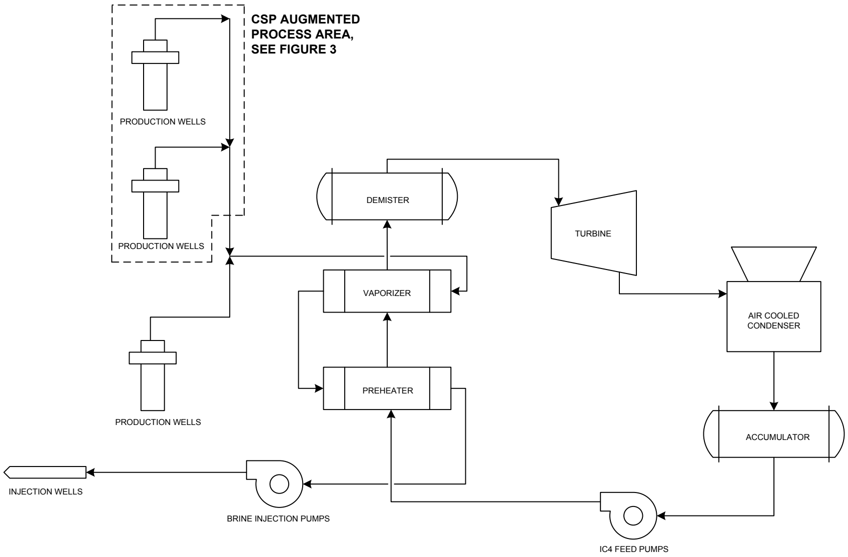

Figure 1: Simplified Stillwater geothermal power plant process flow diagram.

3. SOLAR PV

Geothermal power output suffers during the hot summer days due to the poor cooling offered by the air-cooled condensers. Nevada, one of the sunniest states in the United States, has a project site near Fallon that is endowed with plenty of sunshine throughout the year. The land around the plant owned by EGP-NA is flat and requires very little grading work to make it suitable for installation of solar panels.

The solar PV plant, consisting of 89,000 solar panels, covers 240 acres. Adding solar to the existing geothermal plant not only increased the plant's output by as much as 26 MW, it also made Stillwater a hybrid power plant and the first solar-geothermal hybrid power plant in the world. This innovative project received several awards, including an annual award for "Top Plant" from *Power Magazine*, where it was stated the combination of generation technologies stabilizes production and reduces investment risk (Brady, 2012). EGP-NA with this project also won the Geothermal Energy Association Honor Award for "Technology Advancement" in 2012 and was a finalist for the 2012 Edison Award for "Leadership, Innovation and Advancement in the Industry".

The solar PV project size was tailored to complement the geothermal plant output degradation during hot summer temperatures when the air-cooled geothermal binary plant output is affected by the increased ambient temperature. The solar PV component evens out the dip that occurs in the summer. It demonstrates how a single power plant can deliver renewable solar generated peak and geothermal generated base load power.

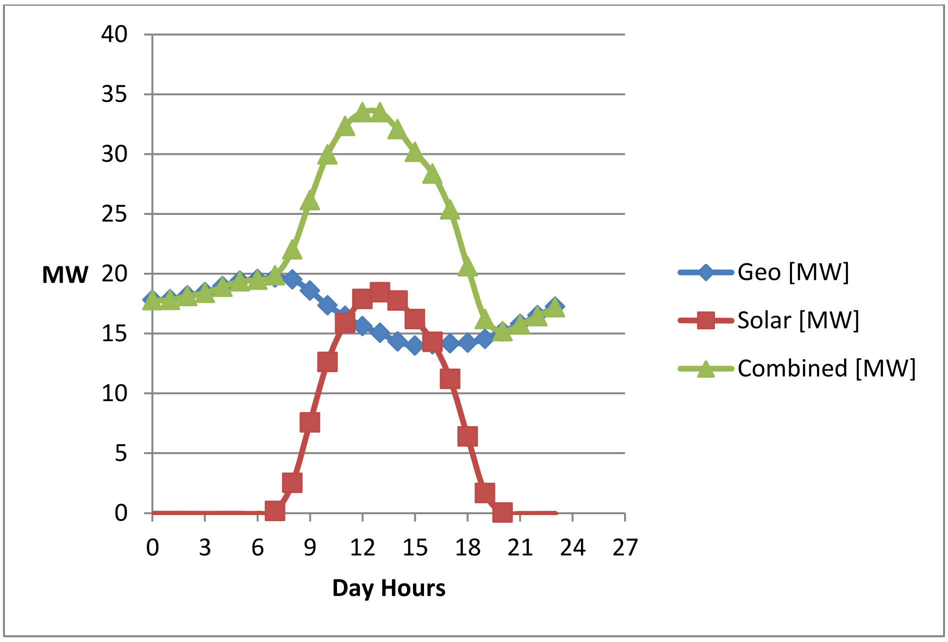

Figure 2: Geothermal and solar PV output net average production for a typical spring day.

4. SOLAR THERMAL

In 2013, design began to add thermal energy to the geothermal power plant. This time, instead of solar PV technology, concentrated solar thermal technology was added. Solar thermal-geothermal hybrid designs have been a topic of many studies (e.g. Greenhut, 2010), but there have been few implementations. Alvarenga et al. describe a small R&D pilot plant at Ahuachapan that produced approximately 0.1 kg/s for a flash plant. This project relied on the circulation of Therminol 55 heat transfer fluid to add energy to separated brine that was subsequently flashed (Alvarenga, 2008).

The solar thermal application at Stillwater relies on linear parabolic trough systems to add energy to increase the temperature of the incoming geothermal fluid to the plant, which allows the binary plant to increase output. The project has reached the highest level of integration with the existing facility, an innovative and cost-effective design that makes it the first of its kind in the world. Installing Concentrated Solar Power (CSP) to heat and return the temperature of the geothermal brine from the wells to its original design temperature is a lower risk approach compared to the historically higher risk of drilling additional wells at Stillwater to recapture the full capacity and economic value of the existing facility. Furthermore, the entire CSP philosophy is based on the principle to not create disruptions to the operating commercial facility. It is anticipated that using CSP will slow the depletion and extend the life of the geothermal reservoir and therefore delay or reduce the need to drill additional production and injection wells for the life of the plant—one of the advantages noted by Nelson and Larsen (Nelson, 2013). Churchill County, where Stillwater is located, is also well suited for CSP due to its dry climate with high solar radiation.

The project consists of collectors, a heat exchanger, a circulating pump and a control system integrated with the geothermal plant. The solar augmentation is expected to boost power output by an estimated 2 MW during the peak of generation.

POWER provided the detailed engineering services for this unique project to install a CSP system to heat a portion of the incoming brine to the Stillwater geothermal plant back to the original design temperature. The CSP system consists of linear parabolic mirrors manufactured by SkyFuel and utilizes treated demineralized water as the heat transfer fluid. Parabolic trough collectors were considered because of their wide operating temperature range capability and scalability.

4.1 Technical Features and Challenges

The size of the CSP plant has mainly been determined to be equivalent to the production of a commercial scale production well. The plant size has been fixed at 17 MW of peak thermal power in order to make the solar plant directly comparable with the average geothermal well in the area in terms of energy delivered (peak conditions).The integration philosophy adopted for the conceptual design has been to minimize the effect on the existing geothermal plant power production of the installation of any new equipment necessary for the hybridization. Because the heat exchanger is the point of connection between the solar and the geothermal plants, a low pressure, drop heat exchanger was utilized to minimize the pressure drop of the geothermal brine through the heat exchanger tubes. This eliminated the need to install in-line booster pumps in the brine line. In-line brine booster pumps would have significantly increased the capital cost, increased the global parasitic consumption of the hybrid plants and made the system inherently more difficult to operate. Low pressure drop is also required because three of the production wells in the wellfield gathering system being augmented are artesian wells. Adding substantial pressure drop would have reduced the flow from these wells significantly and therefore would have introduced a negative benefit to the overall performance of the plant, making the hybridization uneconomical.

The size of the heat exchanger was optimized by matching the flow of the heat transfer fluid (HTF) and the amount of geothermal brine being heated. Approximately 10 percent of the total geothermal brine is sent through the heat exchanger while the remaining 90 percent of the brine bypasses the heat exchanger. The 10 percent brine flow is heated above the desired end temperature such that when it is remixed with the bypassed brine, the resultant mixed design temperature of the combined brine in the common production supply pipeline to the power plant is at the desired increased temperature. Sufficient pressure margin must be maintained to prevent boiling of the brine being heated in the heat exchanger before it is mixed with the brine being bypassed.

The HTF pump is equipped with a variable frequency drive (VFD) to control the HTF flow rate which allows the temperature of the HTF fluid exiting the parabolic mirrors to be controlled to a set point. The VFD on the HTF pump can be run on minimum flow to minimize operating load and to prevent the demineralized water from freezing when the system is not in operation during winter conditions when freezing is possible. In extreme cold conditions, heat from the geothermal brine can be transferred to the HTF fluid to prevent freezing when the CSP mirrors are not in operation.

Scaling of heat exchanger tubes is a concern during cold nights or winter months when there is no heat input from the CSP field but at the same time the HTF loop must be kept in continuous flow to prevent freezing. One way to mitigate this concern is to continuously flow the geothermal brine through the heat exchanger to keep it hot at all time while bypassing the HTF around the heat exchanger. A small quantity of HTF can be diverted through the heat exchanger when needed to maintain a minimum temperature above freezing, keeping the flow low enough to avoid creating a negative impact to the power generation of the power plant.

Demineralized water is utilized as the heat transfer fluid, in lieu of heat transfer oil, to avoid the high capital cost and the ongoing periodic replacement cost of the oil due to degradation. Since Stillwater is a binary-cycle geothermal power plant designed to utilize medium-enthalpy geothermal resource, using heat transfer oil (which can be heated to very high temperature) does not provide significant advantage, compared to using demineralized water heated to a lower temperature in the performance improvement of the plant. The demineralized water treatment equipment is also used for processing raw water for periodic mirror cleaning. Using demineralized water instead of heat transfer oil also has the added benefit of being environmentally friendly.

Nitrogen is used to maintain the HTF loop above the required pressure to prevent flashing. The pressure of the HTF must be optimized to minimize the parasitic load associated with pumping. Higher HTF pressures are required to accommodate higher HTF temperatures which minimize the flowrate and lower the lower pumping power needed to provide the same heat input.

Figure 3 shows a schematic of the process flow.

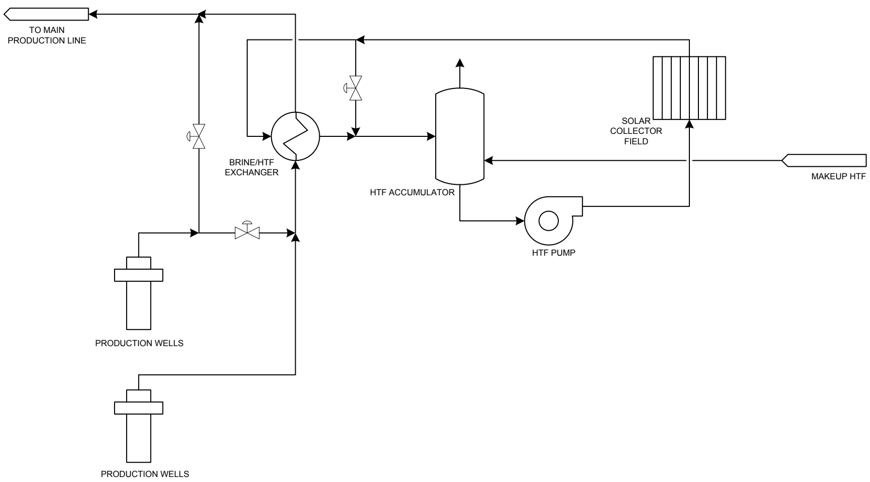

Figure 3: Simplified process flow diagram of the solar thermal augmented section of the Stillwater geothermal power plant.

4.2 Control System Integration

Significant cost saving was realized by having one common control system for both the geothermal power plant and CSP plant. Since the existing geothermal power plant already has a fully functional plant control system, adding the controls of the CSP plant to it only required the addition of some Input and Output cards and programming of control logics into the system. Since POWER was the designer of the control system for the geothermal plant, adding the CSP control was not difficult and took very little time. Final cost of the control system integration was a fraction of what it would cost if a standalone system had been installed (based on bids that were received) because of the minimal hardware that was required to be purchased as well as POWER's familiarity with the existing geothermal plant controls and an understanding of how the CSP controls should be integrated to work seamlessly together.

4.3 Construction and Commissioning

Construction of the CSP field started in the beginning of 2014 and the plant is expected to be fully integrated and commissioned before the end of the year. It is the hope of the authors of this paper that some preliminary operating data will be available for presentation at the Congress.

4.4 Economics

EGP-NA's innovative strategy was to combine several renewable sources at the same location to fully utilize and capitalize on already installed assets to maximize return on investment. In the case of Stillwater, combining several renewable power generation technologies increases output without increasing emission or environmental impact through the sharing of existing infrastructures such as electrical interconnection substation and transmission lines, access roads, control building and other common facilities. Harvey and Ralph described other benefits of co-locating multiple renewable generation types at a facility including having access to more accurate resource and environmental data, reductions in shared O&M costs and the efficient harnessing of "institutional capital" or the knowledge resources of a capable team (i.e. owner/operators, engineers, contractors, government agencies) already familiar with the intricacies of power development and project management at a particular site (Harvey, 2008). Synthesis of this sort into a combined "resource park" may be possible at many existing installations and may be especially attractive at locations with time-of-day pricing.

The solar thermal plant at Stillwater will be capable of generating approximately three million kWh per year, to be added to the power currently being generated by the existing hybrid plant. Combining all three generation technologies is expected to produce approximately 200 GWh of electricity per year. Overall capital investment and installation cost of the solar thermal addition was estimated at $15 million (Enel Green Power, 2013).

5. CONCLUSION

If the conditions are right (e.g. reasonably flat land, good sunlight, etc.), installing geothermal-solar hybrid plants is an excellent option to exploit the best of these technologies to obtain higher performance. EGP-NA aims to analyze the performance of this model plant hybridization at Stillwater and these three proven technologies to determine how best to integrate them technically for future geothermal project development and make them more economically viable.

Integrating solar photovoltaic with a geothermal binary plant using air cooled condensers will increase daytime peak generation. Integrating concentrated solar power with a geothermal binary plant to raise the temperature of the geothermal fluid extracted from the production wells will improve the cycle efficiency and increase its electricity output. Combining the continuous baseload generation of a binary cycle geothermal power plant with both solar photovoltaic and solar thermal technology, fully exploits the characteristics of each technology and uses common, balance of plant systems to increase utilization factor. Stillwater will be the first power plant to incorporate all three renewable technologies.

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