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Flexible Opportunities with Geothermal Technology: Barriers and Opportunities

Geothermal power has typically provided baseload services, which will continue to be important in the future as coal and nuclear power plants retire. However, new developments that increase geothermal power's flexibility will allow geothermal power plants to integrate more effectively in electricity grids supplied by substantial amounts of variable power sources. One key barrier is that current contracts between electric utilities and geothermal operators do not address ancillary services.

Benjamin Matek

Benjamin Matek *is the Industry Analyst at the Geothermal Energy Association (GEA), where he leads GEA's research efforts to prepare several publications and white papers on the industry and renewable energy policy. He received his undergraduate degree from American University, where he studied Economics and Physics, and is currently studying at Johns Hopkins University to receive his Masters in Energy Policy and Climate. Prior to his experience with the Geothermal Energy Association, he worked for the Carbon War Room, a non-profit started by Sir Richard Branson dedicated to finding economical solutions to climate change, and for IHS Global Insight, an economic consulting and advisory firm.*

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I. Introduction

American voters are increasing the pressure on politicians to act on climate change. As examples, renewable energy tax credits and the current public policy debate over the Environmental Protection Agency's 111 (d) Clean Power Plan suggest that renewables are likely to become an increasingly higher fraction of U.S. electricity production in the future.

As renewables continue to integrate into electricity grids nationwide, system operators need to manage the combination of intermittent sources (such as wind and solar) and traditional baseload sources (such as fossil fuel and nuclear sources). In states that produce a significant percentage of power

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from intermittent resources, the need for flexibility extends to traditionally baseload power producers to support stable operation of the local grid. In the power industry, the term ''ancillary services'' is used to express the services necessary to support the transmission of electric power from seller to purchaser, given the obligations of control areas and transmitting utilities within those control areas to maintain reliable operations of the interconnected transmission system.[1] Ancillary services traditionally provided by fossil fuel power plants are beginning to be needed from geothermal power plants, which have historically played a mostly baseload role. This article describes how geothermal power can also provide ancillary services, which can help grid operators to manage the transmission of electricity from suppliers to purchasers within their systems.

Flexibility comes at a cost to geothermal operators, and current policies and power contracts do not incentivize geothermal facilities to operate in flexible modes. With well-structured and appropriately priced contracts, geothermal plants can provide both flexible and baseload power generation. Advancements in power plant and control technology allow geothermal power plants to work in several variable modes, such as grid support, regulation, load following, spinning reserve, non-spinning reserve, and replacement or supplemental reserve. These modes are commonly referred to as ''ancillary services,'' which are performed by entities that generate, control, and transmit electricity in support of the basic services of generating capacity, energy supply, and power delivery.[2] While baseload power has its advantages and unique benefits

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(*see The Benefits of Baseload Renewables: A Misunderstood Energy Technology*)[3] the future electricity grid, dominated by variable energy resources (primarily wind and solar), will place particularly important values on technologies that can be flexible.

Flexible delivery of power has been demonstrated by several projects, including the Puna Geothermal Venture plant in Hawaii. This facility generates 38 MW, and has contracted 16 MW of flexible capacity. Thus, it provides ancillary services for grid support that are identical to those of the existing oil-fired peak generating resources on the Big Island. This geothermal plant is considered to be a first-of-its-kind; however, similar facilities could be developed in Hawaii and elsewhere in the western United States if suitably attractive contracts are in place to support possible reductions in generation and any needed retrofits.[4] Additionally, geothermal plants at the world's largest geothermal field – The Geysers, located in northern California – have operated in various modes, including traditional baseload, peaking, and load following. The flexible modes were offered as an appropriate response to the needs of one of the utilities purchasing geothermal power from The Geysers. Flexible operations ceased in the early 1990s in response to a combination of low demand and lower costs of generation within the utility's system from hydro, coal, and natural gas power plants.[5] However, studies are currently underway to explore new ways to help power plants at The Geysers to again increase their operating flexibility.[6]

These examples are consistent with a 2014 industry survey of geothermal power developers conducted by the Geothermal Energy Association (GEA) that found two primary reasons why most geothermal power plants operate in baseload mode rather than as more flexible sources of electricity:

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1. Sufficient economic considerations to ensure an acceptable return on investment have not historically been offered that would enable geothermal plants to operate in a flexible mode.

2. Storage technology does not yet exist to enable power to be ''banked'' during periods of low demand for later dispatch during periods of high demand; further research and development into storage technology could enhance the ability of geothermal plants to operate in a flexible manner.

For most geothermal power plants, flexibility is an economic issue rather than a technical one. To permit improved modes of dispatching power without yielding market position entirely to natural gas plants, future geothermal power purchase agreements (PPAs) would ideally include provisions that encourage geothermal operators to operate flexibly. Geothermal energy is one of the few renewable energy sources to date that can provide both ancillary services and baseload power without the emissions associated with fossil fuel plants, and should therefore be considered by utilities and grid operators as a favorable option. However, some geothermal plant operators report that low natural gas prices are pricing geothermal plants out of this market.

Some preliminary studies are beginning to define how contracts can promote geo power to be more flexible. One recent study from Livermore Lawrence National Laboratory[7] examined several principles that should be incorporated into future geothermal power contracts to encourage flexibility. Two of these are highlighted below.

- When geothermal plants are intended to be operated in a flexible, load-following mode, contracts should be negotiated to include payment schedules that define the price of power in response to a dispatch signal transmitted by the independent system operator or other load-serving entity.

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- To increase the ability of geothermal plants for frequency regulation (i.e., ramping generation assets up or down over a period of a few minutes), power pricing in future contracts should be negotiated to include payments specifically for frequency regulation services.

Over the course of the researching this article, industry experts suggested these additional ideas that would facilitate flexible operation of geothermal power plants:

- Utilities could buy capacity from a geothermal plant and then purchase energy as they regulate the output of the plant, within its technical limits.
- Flexible contracts with pricing structures that account for geothermal energy's unique capital structure would enable flexible geothermal power to compete with natural gas.
- Utilizing storage technologies for geothermal power plants to store power and release the electricity as needed, instead of constantly exporting electricity directly to the grid would help increase the ability of geothermal plants to operating in various flexible modes.
- Ancillary services in the past have traditionally been provided by fossil fuel sources such as natural gas. In many cases, PPAs for gas projects offer very high prices for ancillary services due to spot market gas purchases. Geothermal offers a more economical alternative, since there is no volatility in fuel pricing.

II. Types of Geothermal Plants and Ancillary Services

Dry steam, flash, and binary (or ORC) are the three main types of geothermal power conversion technologies. In dry steam technology, steam is withdrawn directly from a subsurface

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geothermal reservoir and used to run the turbines that power the generator. In flash plants, high-temperature geothermal fluids are allowed to separate (''flash'') into two phases (steam and water) as pressure drops in the reservoir, in the well, and/or in a surface pressure vessel (''separator''). The steam is delivered to a turbine that powers a generator and the resulting condensed steam and separated water are injected back into the reservoir. In binary or ORC (Organic Rankine Cycle) plants, geothermal fluid does not go through the pressure drop that causes flashing, but is kept in the liquid phase throughout the power cycle. The geothermal liquid is used to heat a secondary liquid called a working fluid, which boils at a lower temperature than water. Heat exchangers are used to transfer the heat energy from the geothermal fluid to the working fluid, which vaporizes and passes through a turbine, driving the generator. The working fluid is then condensed and recycled through the heat exchangers and turbine repeatedly, in a closed loop with zero emissions. The geothermal liquid takes a ''once-through'' path; downstream of the heat exchangers, it is injected back into the reservoir to help maintain pressure. As for the other power conversion technologies, there is complete isolation between geothermal fluids and groundwater sources.

The range of ancillary services provided by geothermal technology can be divided into several broad categories. However, the flexibility of a geothermal power plant can depend not only on the power plant type, but also on the subsurface resource that supplies it. Individual geothermal resources are unique, with wide variations in depth, temperature, chemistry, pressure, permeability, and other characteristics. This means that any two fields in the same county, state, or local area could be vastly different from one another. However, one ancillary service that all geothermal power plants can provide is the grid frequency stabilization during a disturbance, within utility specifications, thereby improving the ability of the utility system to ride-through the disruption.[8]

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Additionally, while it is physically possible for a geothermal power facility to provide spinning, non-spinning, and supplemental reserve, operating in these modes is unlikely to be economical under traditional power purchase agreements. Contract terms would have to be modified for geothermal power facilities to be compensated for the reduced operating time associated with a reserve facility.

A. Ancillary services from ORC geothermal plants

An Organic Rankine Cycle (ORC) based geothermal power plant can be equipped with the telemetry and controls required for automatic governor control (AGC) operation. With predetermined unloaded capacity, it can also respond to upward and downward regulation signals. When an ORC plant needs to operate in a flexible mode, a turbine bypass is used to relieve pressure from the vaporizer. The motive fluid is the fluid in the ORC plant that absorbs heat from the geothermal brine and is vaporized in the heat exchanger to turn the turbine.[9]

For example, at the Puna Facility in Hawaii, remote control capability is accomplished through communication between the Hawaii Electric Company's system operator AGC and the Puna facility System Control and Data Acquisition (SCADA) system. The communication between these two computerized control systems enables, automatic adjustments to the plant generation to match grid demand, in coordination with other generation facilities

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connected to the grid. The communication also allows the plant SCADA system to update the system operator on available capacity and spinning reserves. As a result, the contracted ramp rate (up or down) is set at 2 MW per minute.[10]

In general, a normal ramp rate for dispatch on an ORC facility is 15 percent of nominal power per minute. The ramp rate for dispatch in a flexible operating mode can be as fast as 30 percent of nominal power per minute.[11] Additionally, unlike flash and dry steam plants discussed in the next two sections, operating an ORC in a flexible mode does not normally raise operation and maintenance (O&M) costs.[12]

B. Ancillary services from flash geothermal plants

There are several identified methods to date used to operate flash plants flexibly. The first involves venting steam or otherwise bypassing the turbine, while continuing to operate the wellfield normally. So for example, a plant required to operate at 95 percent rated load with the capability of rapidly increasing load by 5 percent would vent or divert from the turbine 5 percent of the steam. The benefit of this method is it can be implemented quickly. However, the drawback is that allowing a flash plant to ramp and load follow in this manner can lead to a slight increase in operations and maintenance (O&M) costs. Additionally, this method has the potential to accelerate the rate of resource depletion.

The second and more ideal method, which conserves the resource but is less suitable for rapid load changes, is to gradually throttle back multiple production wells to reduce the total geothermal fluid flow to the plant.[13] With this method geothermal resources are conserved, ensuring, the sustainability of a geothermal field. The drawback is cycling geothermal wells in this way can lead to expansion and contractions that stress the bonds between the casing and the cement that provides well integrity. In extreme cases, thermal cycling could cause casing collapse or parting of the casing at its couplings.[14]

For dry steam facilities, compensating a geothermal operator for additional O&M costs would help enable these plants to operate more flexibly.

While there are several ways to operate flash plants flexibly the published ramp rate for flash plants is about 2 percent to 5 percent nominal power per minute at typical running loads, although ramping from a cold start generally takes longer.[15]

C. Ancillary service from dry steam geothermal plants

For dry steam facilities, compensating a geothermal operator for additional O&M costs would help enable these plants to operate more flexibly. It is generally possible to cycle, ramp, and load-follow with dry steam plants, although past experiences with using geothermal technology in this manner have shown increased O&M problems with equipment and systems.[16] Studies are currently underway to find ways to improve the flexibility of dry steam geothermal facilities.[17]

Historically, in the 1990s Northern California Power Agency (NCPA) operated its 150 MW power plant at The Geysers in a load-following mode in which nighttime generation was reduced to about 50 percent of daytime full load. When Pacific Gas & Electric operated portions of the Geysers they also did a significant amount cyclic operation where they did AGC, load following, spinning reserve, and provided capacity. From this experience they operators found there was some increase costs of the steam field when cycling/load following but with little to no cost increases in power plant itself.[18]

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D. Ancillary services coupling geothermal plants and storage technology

The logic behind coupling geothermal plants with storage technology is that it might be uneconomical to ramp or load-follow with a geothermal plant because of higher O&M costs. Storage technology used in conjunction with baseload geothermal would permit conservation of the resource while storing power from geothermal power in off-peak hours and then realizing power during peak demand periods.

A preliminary study from Pacific Northwest National Laboratory[19] has explored some of the opportunities and barriers of coupling geothermal technology with compressed air energy storage, thermal storage, and methane combustion. Overall the study found coupling these systems, total project costs ranging from $1,584/kW to $2,554/kW. These estimates are quite low when compared to the normal capital costs of a geothermal project today because the author assumes some exploration before project construction. However, while affordable, projects that couple these two resources meet the following two main challenges.

- Places where these compressed air storage and geothermal resources overlap typically pose other siting issues including lack of infrastructure availability, lack of market need for energy storage, or lack of available data.
- While economically feasible, the use of sedimentary reservoirs for compressed air energy storage is likely to be limited by complex geology in areas with significant geothermal resources. The economic attractiveness and technical

feasibility of combining compressed air storage and geothermal power would be greatest in location where the geology supports both concepts. Geothermal reservoirs in deep sedimentary basins would be one such location.

However, the study does conclude that coupling these systems could be particularly economically attractive where the geologies match to build them in conjunction with one another. Although this research is still developing, more research is necessary to study the possibilities of coupling geothermal plants with different storage technologies such as battery storage.

III. Conclusion

The technology to provide ancillary services is available for most operating geothermal power plant facilities today, and likely for many new geothermal power plant facilities. However, usually there are economic reasons working against these options. Simply put, the reason geothermal power rarely operates in a flexible mode is that current contracts between electric utilities and geothermal operators do not address these ancillary services. Utility companies or balancing authorities that wish to contract for flexible geothermal resources can do so with confidence, and should be prepared to structure solicitations and offer contract pricing accordingly.

Geothermal power remains one the cleanest energy resources with some of the lowest land use of any energy technology, including other renewable sources. Although traditionally a baseload source of electricity, which will continue to be important because of retirements of coal and nuclear resources, geothermal power can and does offer flexibility. Increasing the flexibility in generating and dispatching geothermal power can be achieved through appropriate pricing structures that recognize geothermal power's up-front costs and acknowledge its

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stabilizing influence on power grids. Geothermal power producers have already demonstrated the ability to operate flexibly, and geothermal facilities engineered and/or incentivize to do are fully capable of providing ancillary services such as regulation, load following, spinning reserve, non-spinning reserve, and replacement or supplemental reserve.■

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