Design and Implementation of the Gümüşköy Hybrid Geothermal and Solar Thermal Power System


1BM Holdings Inc. Ankara/Turkey
2Temiz Yaratıcı Teknolojiler (TYT), İstanbul/Turkey
3Center for Solar Energy Research and Application (Günam), Middle East Technical University (METU), Ankara/Turkey
caglan.kuyumcu@bmmuh.com.tr • onur.serin@bmmuh.com.tr • cihan.ozalevli@tytenergy.com
dbaker@metu.edu.tr • kazim.somek@tytenergy.com

Keywords
Geothermal, concentrating solar thermal, hybrid, parabolic trough

ABSTRACT
A pilot hybrid geothermal-solar thermal energy system was installed in the Gümüşköy Geothermal Energy Power Plant in Aydın, Turkey, in order to explore the performance enhancement of the solar system to total electricity output of the plant and validate a model that is developed to predict the performance of the hybrid system. Tests were conducted on a 200 kWth Parabolic Trough Collector system and results are presented. A post feasibility study for adding a 1 MWs solar field to the existing 5.5 MWe basic binary geothermal system with Organic Rankine Cycle is carried out by considering the test results and performing an economic analysis.

1. Introduction
The demand for electricity has been increasing rapidly throughout the world, especially over the last 10 years. As seen in Figure 1, the yearly total electricity production in Turkey has nearly doubled between 2002 and 2012 from 132,600 to 242,000 GWh. In order to compensate for this increasing demand, there have been large investments in electric power plants in Turkey, especially from the government to support new Hydroelectric Power Plants.

The installed capacity of hydroelectric power plants in Turkey reached 22.3 GW in 2013 and contributed 1/3 of the total energy production in Turkey as shown in Figure 2. According to the government’s 2023 target for renewable energy sources, investments for geothermal power generation will continue to increase. Figure 2 shows that the current installed geothermal capacity of Turkey covers only 0.5% of the total energy production.

Figure 1. Yearly Total Electricity Production in Turkey.[1]

Figure 2. Share of the Energy Resources in the Total Energy Production in Turkey in 2013.[2]

PricewaterhouseCoopers Turkey declared that Turkey has the highest geothermal resource potential in Europe and is among the top 5 countries in geothermal heating applications.[3] The geothermal resources and application map of Turkey is shown in Figure 3 and as is seen, most geothermal resources are in the Western part of Turkey.

The total geothermal potential of Turkey is declared as 31,500 MW by the Ministry of Energy and Natural Resources.[5] As is shown in the distribution pie chart shown in Figure 4, the Western region of Turkey has nearly 4/5 of all geothermal resources. According to the budget plan that the Ministry of Energy and Natural
Resources of Turkey announced in December 2013 for 2014, 94% of the geothermal resources in Turkey are only feasible for thermal usage which means that the reservoir temperature is between 40 and 120°C. The remaining 6% of the geothermal resources are assumed to have reservoir temperatures higher than 120°C. At these higher temperatures, electricity production becomes feasible with the usage of binary cycles, and single and double flash geothermal power plants. The estimated geothermal power potential for these resources is about 2,000 MWₑ. By 2013, there were 13 geothermal power plants constructed with a total capacity of 310.8 MWₑ. Companies in the energy industry in Turkey have licenses for 706.4 MWₑ and this value is expected to increase to 1,000 MWₑ by 2018. This value is higher than Turkey’s 2023 geothermal target, which is 600 MWₑ constructed capacity. This clearly shows that the geothermal industry has been growing faster than was expected.

The solar resources of Turkey and locations of operational geothermal electric power plants are presented in Figure 5. As is seen in Figure 5, 12 of the operational 13 geothermal power plants in Turkey are located in the southwest region of Turkey, which also has an average of 1600 – 1750 kWh/(m² year) of solar resources. Therefore, solar energy can be used to increase the dispatchability of geothermal power plants. Also, a frequently faced problem in geothermal power plant technology is that the reservoir temperature or pressure might decrease after the commissioning of the plant, which turns the designed turbine into an oversized one. In order to have more economical and efficient usage of turbines and other power conversion equipment, another thermal source can be used together with geothermal to compensate for under-performing or degraded geothermal resources.

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Solar thermal systems are applicable for hybridization of geothermal resources since the temperature range and the power conversion technologies are similar. The three most commercially mature solar thermal technologies of parabolic trough, power tower. The land requirement for Parabolic Trough Collectors
(PTC’s) is small when compared with the power tower and Fresnel technologies, which is especially important when the high land prices in geothermal zones are considered. Additionally, among the three solar thermal technologies PTC’s were identified as the most reliable and efficient, and therefore the most appropriate for integration in a geothermal electric power plant.

BM Holding has constructed a geothermal power plant in Gümüşköy, Aydın, in Turkey. The total gross capacity of the power plant is 13.2 MW, with 2 identical ORC units. Each ORC unit consumes 1.1 MWe for internal usage (Pumps, Air Cooling Towers etc.). Therefore, the maximum power output for each unit is limited to 5.5 MWe. Greenhut (2010) states that the power plant production for a reference Geothermal Energy Power Plant may decrease about 40% below the nominal value at noon hours in summer months [8]. The designed (nominal) and expected power outputs based on variations in ambient temperature for one ORC unit of the Gümüşköy Geothermal Power Plant are shown in Figure 6. When the effect of ambient temperature is considered, the expected production exceeds the designed production for months which have lower average ambient temperature values than the design ambient temperature of 20°C.

The main reason for the difference between the expected and actual electricity production is the deviation of the production geothermal reservoir temperature from the design temperature.

Enel Green Power has been working on a hybrid geothermal-solar power plant in North America’s Stillwater geothermal power plant. It is stated that “The solar field is designed to return the temperature of the brine from the geothermal wells to its original design point and thus recapture the full capacity and economic value of the existing turbine generator” [9]. Therefore, it is seen that the geothermal wellhead production temperature may decline from the drainage temperature over time, and the decrease in the wellhead temperature results in a decrease in the turbine performance. Therefore the problem of geothermal resources declining with time is not unique to the GGEPP.

BM Holding in partnership with Temiz Yaratıcı Teknolojiler from Turkey conducted a feasibility study to overcome the thermal mismatch problem between the design and production geothermal wellhead temperatures. A hybrid geothermal and solar thermal power plant (GeoSolar) is proposed and this project is supported by the Scientific and Technological Research Council of Turkey (TÜBİTAK). In the scope of this project, a pilot PTC field with a capacity of 200 kW<sub>e</sub> was constructed and placed into operation. In this paper the design and installment processes are explained, results are discussed and a post feasibility study presented for a larger application of the PTC field.

2. Design, Installment, and Results

The GGEPP is located in the Ortaklar province of Aydın, approximately 40 km west of the Aydın city center and 80 km south of the Izmir International airport. The location of the GGEPP and a general view from the field is shown in Figure 7. The first limitation about determination of the scale of the solar field was area. In order to observe the effects integrating solar thermal to the geothermal brine and avoid any piping losses, the solar field needed to be located close the geothermal pipeline. In order to maximize the total thermal

Figure 6. Trends in the Actual (Measured in the power plant, December 2013–April 2014), Designed, and Expected (Due to Ambient Temperature Change) Electricity Production of the Gümüşköy Geothermal Power Plant and Locally Measured Monthly Total Direct Irradiance throughout year.

Direct Normal Irradiance (DNI) is being measured onsite and the monthly total DNI is presented also in Figure 6 with the actual electricity production of Gümüşköy Geothermal Energy Power Plant (GGEPP) for 5 months (Dec. 2013-April 2014). It is clearly seen that the actual electricity production is less than the expected mainly because of the mismatch between the designed geothermal brine temperature and the actual one. The 1<sup>st</sup> unit of GGPP is operational and uses geothermal brine from 2 wells. The average brine temperature was measured as 165°C during the drainage, therefore, the sizing of the turbines were carried accordingly. However, subsequently the average temperature of the brine has been measured around 156°C.

Figure 7. Location and View of BM Holding’s Gümüşköy Geothermal Energy Power Plant in Aydın, Turkey | Latitude: 27.27 E Longitude: 37.51 N. The location of the PTCs is circled.
output for the solar field throughout year, the orientation of the PTC was fixed to track in the East-West direction. The location of the PTC’s is shown with the red circle in Figure 7.

Skyfuel’s Skytrough collector was chosen as the PTC technology after evaluating different options by considering the cost, performance, logistics and ease of assembly of the products. The maximum number of modules that fit in the determined area was calculated as 3. The resultant total aperture area of solar concentrators is 246 m², which has nearly 200 kWth capacity. After the determination of the solar thermal capacity, the components that will be used in the closed solar cycle were determined. The connection interface between the geothermal and solar cycle was studied. In order to avoid any negative effect on the ORC cycle of the power plant, it was decided that the safest and most observable connection would be heating of the geothermal brine with the thermal energy that is collected by solar field.

Before designing the system and determining the operating conditions, a study was conducted in the Heat Transfer Fluid loop of Plataforma Solar de Almeria (PSA) with the support of a SFERA grant. The solar system professionals at PSA helped identify the main design requirements for the PTC’s.

Details about the design of the system are as follows.

Selection of the Heat Transfer Fluid

The Heat Transfer Fluid (HTF) that is circulated in the closed solar cycle is determined by the temperature requirement at the inlet of the heat exchanger that transfers the thermal energy of the solar field to the geothermal flow. The temperature of the geothermal brine is about 156 ± 2°C throughout the year. In order to have efficient heat exchange, the outlet temperature of the solar field is chosen to be slightly higher than 300°C. Any additional temperature increase would result in higher heat losses to atmosphere from the solar field. For this specific application, a synthetic oil, Therminol 62 was chosen in order to keep the flow in the liquid phase at pressure below 1 bar absolute. This allowed for a lower pressure rated piping system and a lower cost for the entire system.

A detailed design analysis was carried based on the Therminol 62 HTF and the chosen operating conditions are presented in Table 1.


A simple schematic of the proposed system is shown in Figure 8 with the required BOP equipment needed in order to have a safer operation. In order to circulate the fluid a gear type pump is chosen. It was required to have an appropriate seal in order to avoid any leakages and vaporization at high temperatures.

A shell and tube type heat exchanger (HEX) was chosen for the interface between the solar system and geothermal flow. The materials are determined so that the corrosive behavior of the geothermal flow could be managed. During the startup period of the system, the HEX is used as a warm-up bypass in order to heat the HTF of the solar field up to 150°C by using the energy from geothermal flow. Once it is heated, the bypass valve is opened by using a pneumatic 3-way valve, so that the temperature of the HTF increases further by using solar resources.

An expansion tank is a pressurized void within the system that provides a location to hold any excess HTF introduced during the initial filling and to accommodate changes in the HTF volume as it is cycled between the ambient and operating temperatures each day. This component is also used to regulate the pressure inside of the loop by providing a net positive suction head for the pump. The reservoir remains at a higher pressure range than both the vapor pressure and solar loop pressure. The required pressure of the expansion tank is determined to be 2 bars and is achieved with the help of nitrogen that is supplied from the top of the expansion vessel.

Since the system is designed as a pilot system which is capable of running at different operating conditions with different HTFs, a...
carefully sized reservoir tank is used. Also, it is important to have a line that allows the HTF to flow through the expansion tank to the reservoir tank. When the HTF is allowed to pass through the void space in the expansion vessel, vaporized HTF within the flow are vented through the void to the reservoir tank and removed from the HTF.

In order to observe the performance of the system accurately, temperature, pressure and flow sensors are located as shown in Figure 8. The number and type of the sensors are given in Table 2.

**Installation of the System**

Installation process was carried out in 2 steps. The first step was to complete the installation of the PTC field. Before the mechanical assembly of the components started, civil and electrical works were completed. The foundations for the pylons were poured, drainage canals were constructed and electrical lines that are necessary for tracking were wired.

The mechanical assembly of the collectors was completed easily with the usage of rivets and rivet guns that pull and join the components together and increase the speed of assembly. Figure 9 shows 3 pictures taken during the installment of the PTC field. In the 1st picture the space frame that supports the collector is formed and 3 frames are hanged in the 2nd picture. The 3rd picture in Figure 9 is taken right after the installment of the reflective mirrors was completed for the 1st module.

The installment of 3-module PTC field was completed in 8 total working days with 4 inexperienced labors. In the 2nd step of the installment process, pipelines in the PTC field and connection between the HEX and geothermal brine were constructed. The completed view of the PTC field from top with GGEPP is shown in Figure 10 and 11.

**Test Results**

Field test results are presented in this section in terms of the collector efficiency. Experimental collector efficiency ($\eta_{col\exp}$) is calculated instantly by using Eqn. (1) where $m_{HTF}$ is the mass flow rate of the HTF circulated in solar loop, $Q_{solar}$ is the total energy input in the solar loop.

<table>
<thead>
<tr>
<th>Data Sensor</th>
<th>Number</th>
<th>Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature</td>
<td>6</td>
<td>PT100</td>
</tr>
<tr>
<td>Pressure</td>
<td>6</td>
<td>Pressure Transmitter</td>
</tr>
<tr>
<td>Flow</td>
<td>1</td>
<td>Calibrated Orifice</td>
</tr>
<tr>
<td>Level Gauge</td>
<td>2</td>
<td>Magnetic Level Gauge</td>
</tr>
<tr>
<td>Dry Contact</td>
<td>2</td>
<td>Float Dry Contact</td>
</tr>
</tbody>
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Table 2. Number and Type of the Data Sensors shown in Figure 8.
energy captured from the sun by the receiver (Eqn. (2)), \( h_{\text{out}} \) and \( h_{\text{in}} \) are the enthalpies at the outlet and inlet of the solar loop that are calculated by using a property model in which temperature measurements are used, respectively.

\[
\eta_{\text{coll}} = \frac{m_{\text{HTF}} \times (h_{\text{out}} - h_{\text{in}})}{Q_{\text{solar}}} \tag{1}
\]

\[
Q_{\text{solar}} = A_{\text{coll}} \cdot G_{\text{in}} \cdot \cos \theta_d \tag{2}
\]

\( A_{\text{coll}} \) and \( G_{\text{in}} \) stands for the collector total aperture area and direct irradiation data that is measured on site, respectively. The tests were conducted on 20th of May 2014, however, since the weather station was not implemented on site, direct irradiation data was not collected for the exact date. The experimental heat gain is calculated by using the numerator of the Eqn. (1) and results are shown in Figure 12.

As it is seen from Figure 12, the maximum solar field outlet temperature reaches to 250°C at about 4 pm. The solar resources were very transient at the test day. In order to calculate the efficiency of the system, further tests will be conducted.

McMahen, White, Gee and Viljoen (2010) predicted the collector efficiency (\( \eta_{\text{predicted}} \)) for Skytrough PTC’s by carrying out adjustments to the optical efficiency (\( \eta_o \)) which is calculated at normal incidence. Eqn. (3) uses angle of incidence (\( \theta_d \)) and incidence angle modifier (IAM(\( \theta_d \))) in order to include the effect of non-zero angle of incidence.

\[
\eta_{\text{predicted}} = \eta_o \cdot \text{IAM} - Q_{\text{loss}} \tag{3}
\]

The optical efficiency of the collector (Eqn. (4)) was tested and the incidence angle modifier without cosine losses (Eqn. (5)) is found by Gawlik, Stynes and Kutscher (2010).

\[
\eta_o = 0.773 \tag{4}
\]

\[
\text{IAM}(\theta_d) = (3 \cdot 10^{-5}) \cdot \theta_d^2 - 0.0002 \cdot \theta_d + 1 \tag{5}
\]

In order to compare the experimental data with the predicted performance, heat loss from the receiver to environment (\( Q_{\text{loss}} \)) should be calculated. In Gawlik’s study (2010), Schott PTR 80 receiver is used and loss is calculated. In the GGEPP project, Huayan receivers are used and relationship between Schott and Huayan will be calculated after the test results are obtained and implemented in this model.

The error between the predicted and the experimental collector efficiency values () will be calculated by using Eqn. (6).

\[
\varepsilon_{\eta,\text{coll}} = \frac{(\eta_{\text{predicted}} - \eta_{\text{coll}})}{\eta_{\text{coll}}} \tag{6}
\]

3. Post Feasibility

A post feasibility study will be carried out by considering the experimental results of the solar field. The total thermal output for 1 MW, solar field will be calculated and economics of such a system will be analyzed by taking subsidies for concentrated solar thermal in Turkey. The return of investment value will be calculated for the hybrid system that is planned to be constructed in GGEPP.

4. Conclusion and Future Work

In the Design Section, the thermal and field design of the pilot system is presented. This design will be optimized and expanded for a 1 MW, CSP system and the requirements will be determined in order to have a better understanding about the economics of hybrid geothermal and solar thermal systems. First test results and investment costs show that the project feasibility for the pilot project is consistent to real application. If the test results about the performance of the hybrid system meet the expectations until October 2014, the decision about the launch of the 1MWc CSP integration will be made. Further experimental study will be carried out throughout a year in order to observe the change in the performance increase of the ORC unit both in summer and winter months.

Acknowledgements

This work is supported with grants from TUBITAK (7120763) and EU-SFERA (228296).

References