Real-time Electric Submersible Pump Machine Learning Diagnostics Enable Scale Detection and Power Optimization in Geothermal Applications

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1. ABSTRACT

Geothermal energy is a highly reliable, eco-friendly, sustainable, and clean energy source that has proven to be a game-changer in the residential and industrial sectors. It can be developed from hot rocks saturated in geologically favorable reservoirs, in which water is produced at temperatures greater than 120 °C from a depth of up to 4 km utilizing an Electric Submersible Pump (ESP).

Due to the flow rates required, high-enthalpy fluids, and harsh downhole conditions of geothermal wells, a real-time Well Manager System was implemented to improve the ESP design, operation, reliability, and well performance. This paper details the operating conditions of a high-efficiency geothermal ESP system in Germany with in-house developed machine learning models.

Our Well Manager System has advanced to obtain virtual measurements, visual operating indices, vibrations tracking, real-time pump, and well performance evaluation, electrical unbalance tracking, and scale detection.

The machine learning models predicted pump intake pressure, motor temperature, fluid temperature, and flow rate, with less than 5% error compared to actual measurements. Additionally, the virtual parameters and real-time total dynamic head were analyzed together to indicate potential scale buildup within the flow meter or downhole components.

A thorough assessment was made by

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continuously monitoring (24/7/365) the enabling recommendations to improve power consumption and increase the ESP's run life.

Keywords: GeoESP® pump, real-time monitoring, machine learning, scale detection, power optimization.

2. INTRODUCTION

Geothermal power is a clean and renewable source of energy from the earth’s crust, which has become an attractive alternative to coal, oil, and natural gas, allowing diversification of the energy matrix in countries where it has been developed. These energy systems are produced from sandstone reservoirs with a moderate-to-excellent productivity index which are usually unable to naturally lift the geothermal fluids to the surface at economically viable flow rates according to the energy demand [1]. To enable reliable water management in geothermal energy production, most operators rely on ESP systems that produce hot brines containing dissolved gas from harsh geothermic reservoirs to surface facilities. physical and digital aspects of the system,

Once the ESP system is deployed in the well, the extreme temperatures, highly abrasive fluids, and corrosive environments [2], [3], [4], represent the principal challenges in high-efficient Geothermal Electric Submersible Pump applications (GeoESP® pump). Additional challenges include scale deposition, solids and abrasives production, fines migration, corrosive-erosive wear, resonant frequencies and high vibration, electrical insulation failure, pump performance tracking, excessive heat, high shafts, and thrust bearings loads. Reliable ESP design to mitigate these issues is a vital part of the economic viability of the project.

This article shares a successful case study of a geothermal well in Germany in which a real-time monitoring cloud system of the ESP allowed the optimization of operating parameters, detection of abnormal trends, avoidance of potential detrimental conditions, recommendations for sizing enhancements, support for the root-cause-failure analysis, and improvement in the reliability of the whole system. To the author’s knowledge, very few works on real-time monitoring of ESP systems in geothermal wells have been published to date [5].

3. METHODOLOGY

3.1. GeoESP® pump application

The installed high-efficiency GeoESP® pump system was designed for a target flow rate of up to 450 m^3/h (125 L/s):

- Mixed-flow centrifugal pumps with Inconel shafts, enhanced tungsten carbide thrust inserts, grooved bushings, unique retaining rings, and Erosion Buster® diffusers that help prevent scale deposition and abrasives recirculation. Given the wide range of operation of the pump, the ESP could maintain constant operation according to the heat requirement for different climatic seasons.
- GeoESP® pump Intake with a metallic mesh to prevent large solids and rocks from entering the pumps, designed for lower pressure drop and enhanced power requirements.
- Defender® Seals with labyrinth chambers, Durahard® 3 corrosion-resistant coatings, and extended expansion capacity to cope with thermal cycling and calcium carbonate scale plugging.
- Tandem motors with mechanical bearings retainers incorporated into large wide-profile Big Foot™ bearings, which allow movement of the rotor stack within the stator and heat transfer during thermal cycling, as well as tungsten carbide radial supports to reduce vibration.
- High-temperature downhole gauge evaluated for the expected harsh downhole environment.

The project can be described as a medium enthalpy doublet system. The ESP equipment was operated uninterrupted from start-up with a stable input power supply and within its recommended design limits.

Fig. 1: GeoESP® pump schematic.

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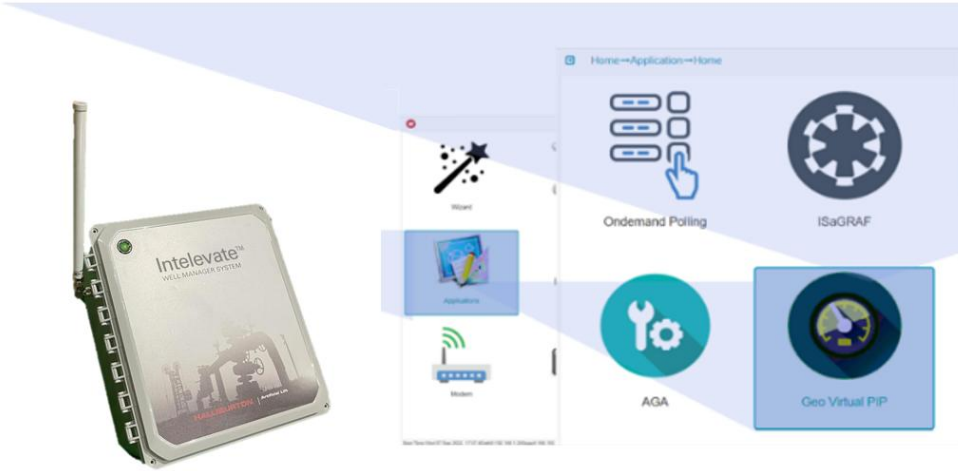

Fig. 2: Machine learning models implementation in the Intelevate™ Well Manager System.

3.2. Monitoring and optimization

The Intelevate™ Well Manager System is a customizable monitoring and collaboration cloud platform that was implemented for geothermal projects surveillance and digitalization of operations with GeoESP® pumps. The platform works with a Remote Terminal Unit (RTU) installed at the well site that serves as an EDGE device for monitoring data capture and computing, event diagnostics, machine learning deployment, and wireless sensor implementation using private VPN encrypted communications. This allows the geothermal plant and the GeoESP® pump to be monitored in real-time from computers, tablets, and cellphones on a 24/7/365 basis.

3.3. Machine learning models

Statistical machine learning processes monitoring ESP systems is a relatively new technology in the oil and gas industry; it allows the prediction of multiple operating parameters with high precision and events detection by combining physical and trained mathematical models adjusted to each well [6]. A wellbore variable is fitted with a selected machine learning technique by using one or a combination of statistical learning models such as linear regression, logistic regression, decision trees, random forest, and neural networks in a time interval that includes a group of monitoring data. The selected model is then validated with data that was not involved in the previous training and the calculations are run in real-time in the

Intelevate™ Well Manager System.

Once the GeoESP® pump is started, around 2-3 weeks of data capture is required, including frequency changes for proper calibration of the machine learning models. In case of downhole gauge failure, the machine learning models enable the backup and continuous monitoring of the ESP with excellent prediction accuracy and low error (<5%), for pump intake pressure, motor temperature, fluid temperature, and produced total dynamic head (TDH).

4. RESULTS

4.1. GeoESP® virtual pump intake pressure

The pump intake pressure (PIP) is the pressure exerted by the well fluid on the sensor head and serves as a critical diagnostic for pump performance as it is a function of flowing bottomhole pressure, fluid level over the pump, fluid composition, static reservoir pressure, flow rate, and productivity index.

Local governmental authorities in Germany require a continuous real-time measurement of this pressure. As shown in figure 3, the implemented Geo Virtual machine learning models can calculate the virtual PIP with less than 5% arithmetic error (less than 2 bar) by considering well conditions, equipment specifications, and past performance.

The monitoring and comparison of this pressure between different installations of the same well allows the evaluation of several things:

- The drawdown profile and time necessary to stabilize the productivity index of the geothermal reservoir (figure 4).
- Detection of stage wear, scale accumulation, solids plugging, fluid recirculation, and productivity index changes (figure 5). This helps identify whether the well requires a lower total dynamic head (TDH) to produce similar flow rates compared to previous runs.
- Recommendation of proactive chemical treatments for scale (figure 6). In this case, a downhole scale treatment was performed after the marked increase in the sensor pump intake pressure and Geo Virtual PIP error because of scale plugging at the intake ports. An increase in error can indicate possible adverse well conditions or

approaching ESP failure.

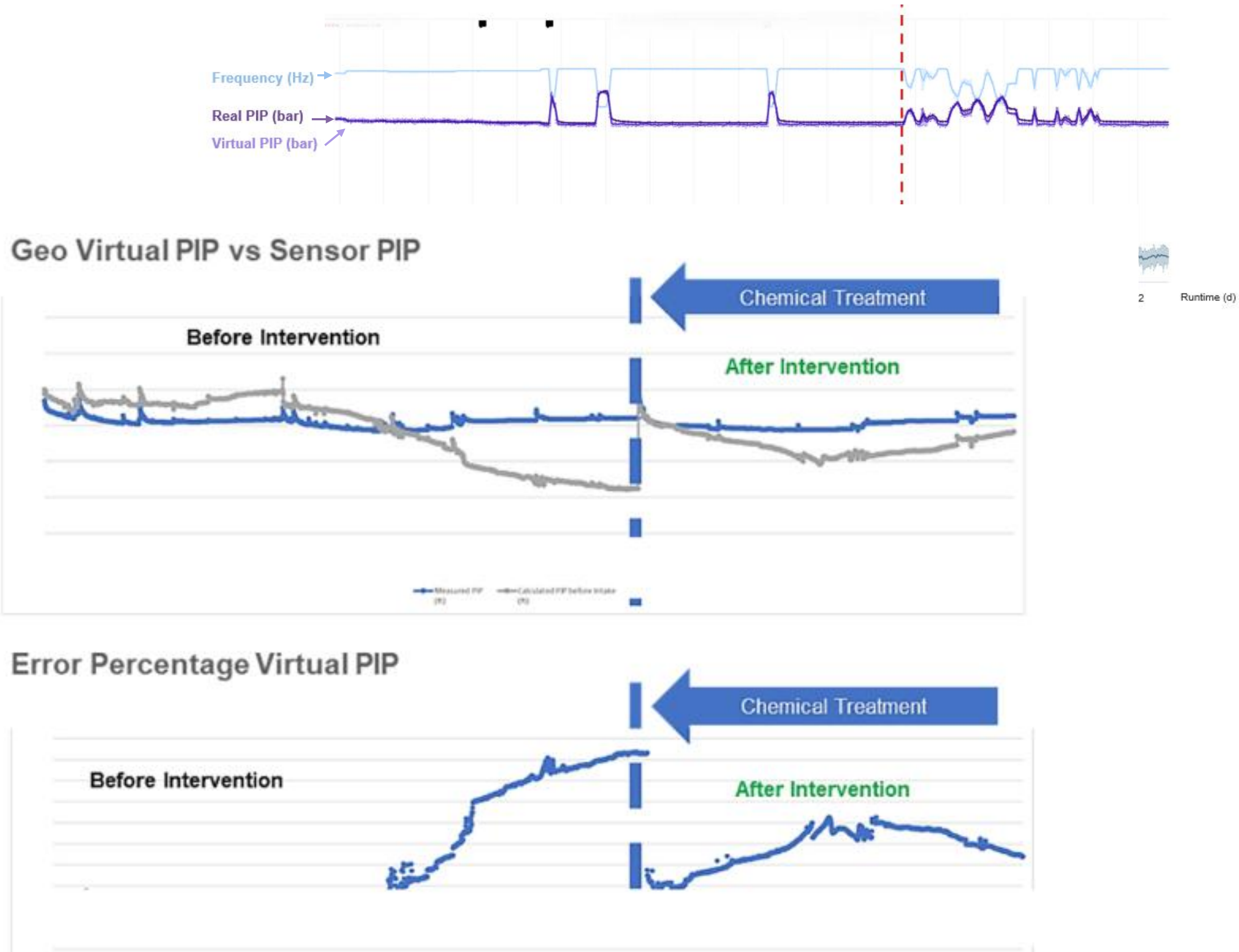

Fig. 6: Proactive chemical treatment based on virtual parameters observations.

Fig. 5: Productivity index tracking.

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4.2. GeoESP virtual temperatures

The motor winding and fluid temperatures are also predicted with less than 5% error (less than 2.5 °C), even during frequency reduction events, as seen by the overlapping curves in figure 7. The high wellbore temperature and scaling tendencies of the produced geofluids determine the baseline on which the motor will run and keeping track of these parameters is especially important for diagnosing organics deposition on the downhole components as well as fluid compositional changes. Exceeding the downhole gauge temperature ratings can cause frozen data at low runtimes.

It is important to have the machine learning models already calibrated with data from the current or previous run to avoid the installation of backup sensors in the production string or additional surface hardware.

4.3. GeoESP virtual flow rate

Predicting flow rate using machine learning techniques is generally more challenging than the other operating variables. Until now, errors of 3% have been achieved, but in some cases, this can reach 5% (figure 8). It is worth highlighting that during frequency changes it has been possible to maintain the accuracy of the predictions. Also, if the surface flow meter is calibrated, it is necessary to recalibrate the machine learning model as well.

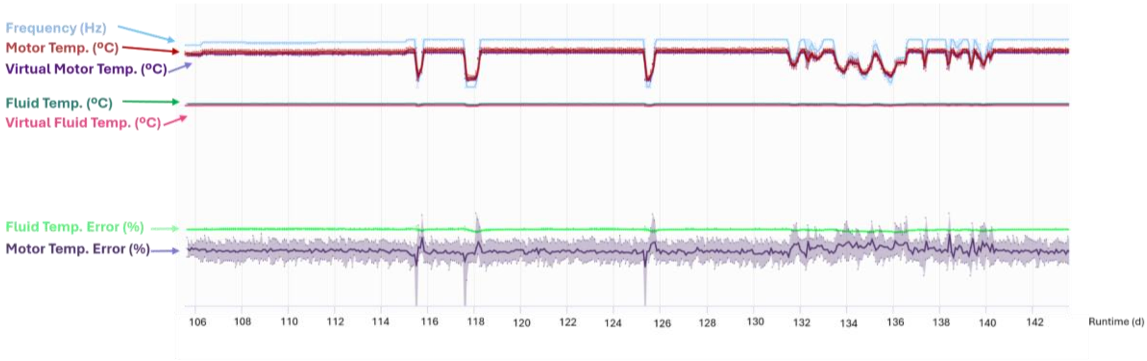

Fig. 7: Geo virtual temperatures tracking.

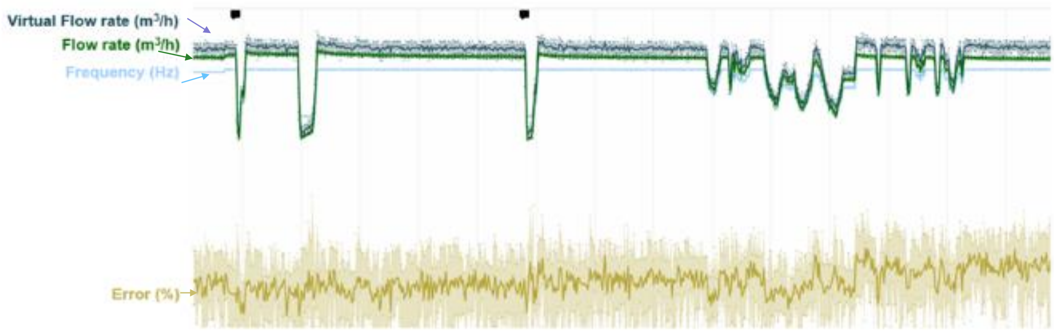

Fig. 8: Geo virtual flow rate tracking.

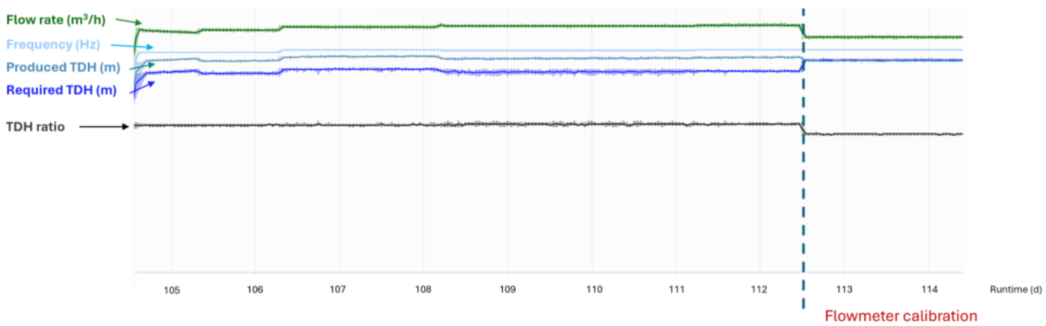

Fig. 9: Required and produced total dynamic head tracking.

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4.4. GeoESP virtual TDH

Considering the dynamic lift height, the friction loss in the tubing, and the necessary lift on the surface, it was possible to implement the real-time calculation of the required TDH [7], as well as the produced TDH based on the installed high-flow pump. The TDH tracking is used for identification of scale deposition on surface lines. In figure 9, after a flow meter calibration, the produced TDH by the pump equalized the required TDH by the well. This is an indicator of scale deposits inside the surface flow meter since its principle of operation is based on the fluid velocity through the cross-sectional area.

4.5. Vibration tracking

The vibration assessment of ESP systems considers that the most important amplitude occurs in the radial orientation, i.e., perpendicular to the length of the equipment since it affects the bearings and the stability of the shafts. In high-production geothermal wells, the vibration is highly oscillatory, and its amplitude must be constantly observed to determine possible resonance frequencies. From historical data analysis, it has been determined that 0.5 G is a limit for peak vibrations in geothermal wells.

Figure 10 shows how the vibration increases when operating the GeoESP® pump at resonance frequencies. Subsequently, it was possible to identify that this range of frequencies generated resonant vibrations; by avoiding it during speed reductions, there was a lower amplitude and peak of vibrations in the X and Y axes.

The significant benefit of monitoring of these parameters is to prevent operation in resonance, which may affect the system's mechanical integrity.

4.6. Electrical unbalance tracking

The output voltages and currents are the electrical energy supplied by the medium-voltage variable speed drive and transmitted by the power cable to the electric submersible motor. In general, it is recommended that the output voltage and current unbalance be less than 3% when running at a steady frequency (figure 11). A deviation greater than 3% could be related to high harmonic distortion, faulty VSD output filters, phase insulation deterioration, ground phases, high leakage current, input power fluctuations, flat cable configuration, cable/splice impurities, manufacturing defects, unbalanced temperature distribution across the motor, buckling/bending, motor frame size, rough handling during shipment or resonance frequencies.

The electrical unbalance is calculated by taking the arithmetic average and comparing it with the value of each electrical phase. In the following example, once the resonant frequencies were avoided during normal geothermal plant operations, it was possible to verify that the electrical unbalance decreased, which is favorable for a longer motor run life.

4.7. Event detection

Early detection of scale development or solids plugging at the downhole intake is performed while running at a constant frequency, based on a TDH and flow drop from expected conditions. Another indicator factor is a rapid vibration increase exactly during TDH changes. Also, from the Geo Virtual PIP calibration it was noticed that the pressure drop across the intake and friction losses were much higher compared to historical data. The combination of these findings is intrinsically related to scale build-up.

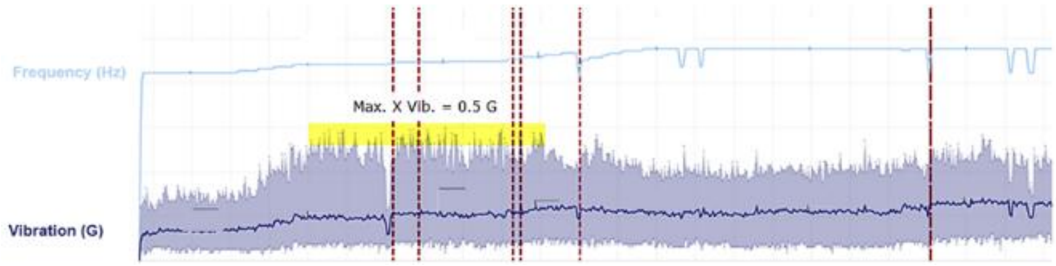

Fig. 10: Vibration resonance.

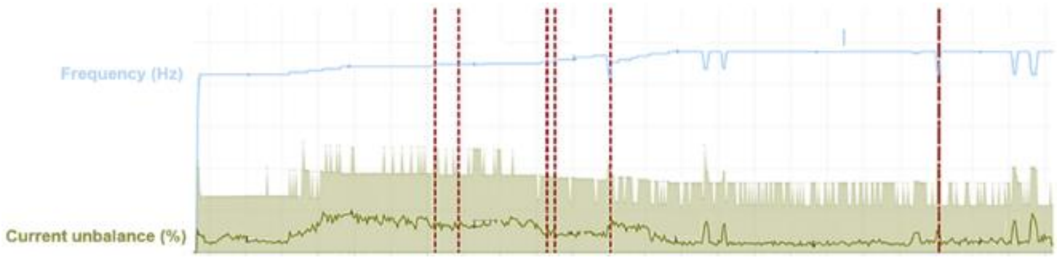

Fig. 11: A-phase current unbalance tracking during resonance frequencies.

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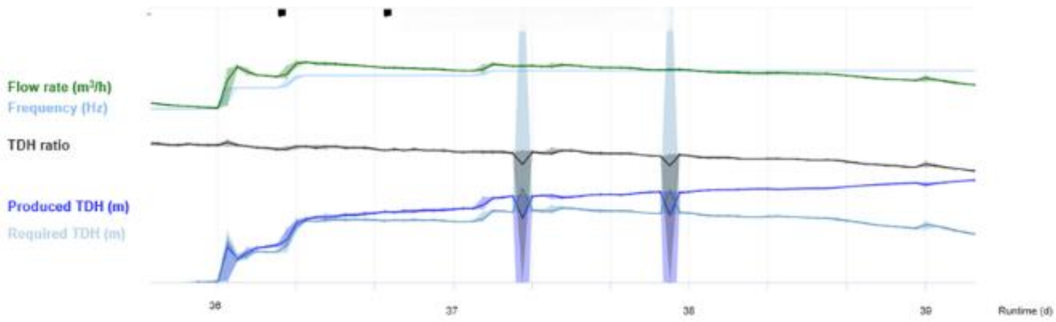

Fig. 12: Scale build-up detection.

5. CONCLUSION

The predicted virtual parameters using machine learning models are within 5% error for pressures, temperatures, and flow rate. The models have been implemented for more than 1500 days with successful results across more than 12 applications. The virtual pump intake pressure, total dynamic head, and vibrations tracking help identify when scaling accumulates in the flow system which is particularly useful for detecting when a chemical treatment is required. In conclusion, the digitalization of the geothermal plant and downhole pump supports the development of rapid decision-making protocols when abnormal conditions arise, preserving the electromechanical integrity of the GeoESP® pump.

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