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# Geothermal Electric Submersible Pump Virtual Parameters Optimize Well Performance Through Real-time Monitoring and Machine Learning Diagnostics

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**Abstract**

Geothermal energy is a highly reliable, eco-friendly, sustainable, and clean energy 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 an electric submersible pump (ESP) produces water at temperatures greater than 120°C from a depth of up to 4 km. Once its heat is converted to electricity in the power plant, the water is cooled and reinjected into the reservoir. Due to the required flow rates, high-enthalpy fluids, and harsh downhole conditions of geothermal wells, a real-time well manager system is necessary 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 and the geothermal ESP well manager system built upon in-house developed machine learning models which predicted pump intake pressure, motor temperature, fluid temperature, flow rate, and overall operating parameters with less than 3% error. The virtual parameters and real-time total dynamic head were analyzed together to indicate potential scale buildup within the flow meter, organic deposition on the motor housing, and changes in fluid composition. As a result, our advanced geothermal well manager system can obtain virtual measurements, visual operating indices, vibrations tracking, real-time pump and well performance evaluation, electrical unbalance tracking, and scale detection. A thorough assessment made by continuously monitoring (24/7/365) the physical and digital aspects of the system enable recommendations for improving efficiency and increasing the lifespan of the ESP.

## 1. Introduction

Geothermal power is a clean and renewable source of energy from the earth’s crust, that 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 and are usually unable to naturally lift the geothermal fluids to surface at economically viable flow rates according to the energy demand (Grant 2013). To enable reliable water management in geothermal energy production, most operators depend on ESP systems that produce hot brines containing dissolved gas from harsh geothermic reservoirs to surface facilities.

Once the ESP system is deployed in the well, the extreme temperatures, highly abrasive and corrosive environments offer major challenges in high-efficiency geothermal electric submersible pump (GeoESP®) applications (Octaviano et al. 2022), (Kullick 2022), (Kullick and Hackl 2017). These 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 as a key part of the economic viability of the project. The purpose of this article is to share 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 (Tandazo et al. 2022), (Octaviano et al. 2022).

## 2. Methodology

### 2.1. GeoESP™ application

The installed high-efficiency GeoESP® 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, special 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.
- Geothermal Intake™ with a metallic mesh to prevent large solids and rocks entering the pumps, designed for lower pressure drop.
- 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, that 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 tested 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 stable input power supply and within its recommended design limits.

### 2.2. Monitoring and optimization

The InteLift™ Well Manager System is a customizable monitoring and collaboration cloud platform that was implemented for geothermal projects surveillance and digitalization of operations with GeoESP™ units. The platform works with a remote terminal unit (RTU) installed at the wellsite, that serves as an EDGE device for monitoring data capturing and computing, events diagnostics, machine learning deployment and wireless sensors implementation using private VPN encrypted communications. This allows the geothermal plant and the GeoESP™ to be monitored in real-time from computers, tablets, and cellphones on a 24/7/365 basis.

### 2.3. Machine learning models

Statistical machine learning processes monitoring ESP systems is a relatively new technology in the oil and gas industry; it allows predicting multiple operating parameters with high precision and events detection by combining physical and trained mathematical models adjusted to each well (Lastra 2019). A wellbore variable is fitted with a selected machine learning technique by using one or a combination of the statistical learning models such as linear regression, logistic regression, decision tree, 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 if the results are acceptable within the deviation probability logic, the

calculated values are stored and implemented in real-time in the InteLift™ Well Manager System (figure 1).
Once the GeoESP™ is started, around 2-3 weeks of data capture is required, including frequency changes for a 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 (<3%), for pump intake pressure, motor temperature, fluid temperature and produced total dynamic head (TDH).


Fig. 1: Machine learning models implementation in the InteLift™ Well Manager System.

## 3. Results

### 3.1. Geo 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 key diagnostic for pump performance as it is a function of flowing bottomhole pressure, fluid level over the pump, fluid composition, static bottomhole pressure, flow rate, and productivity index.
Local governmental authorities in Germany require a continuous real-time measurement of this pressure. As shown in figure 2, the implemented Geo Virtual machine learning models can calculate the virtual PIP with less than 3% arithmetic error (less than 2 bar) by considering well conditions, equipment specifications, and past performance (Tandazo et al. 2022).

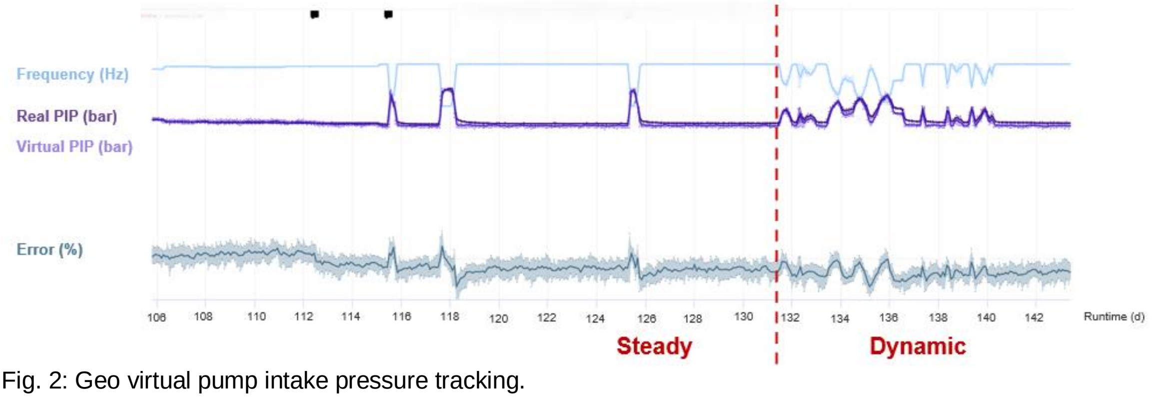


Fig. 2: Geo virtual pump intake pressure tracking.

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

- The drawdown profile and time necessary to stabilize the productivity index of the geothermal reservoir (figure 3).

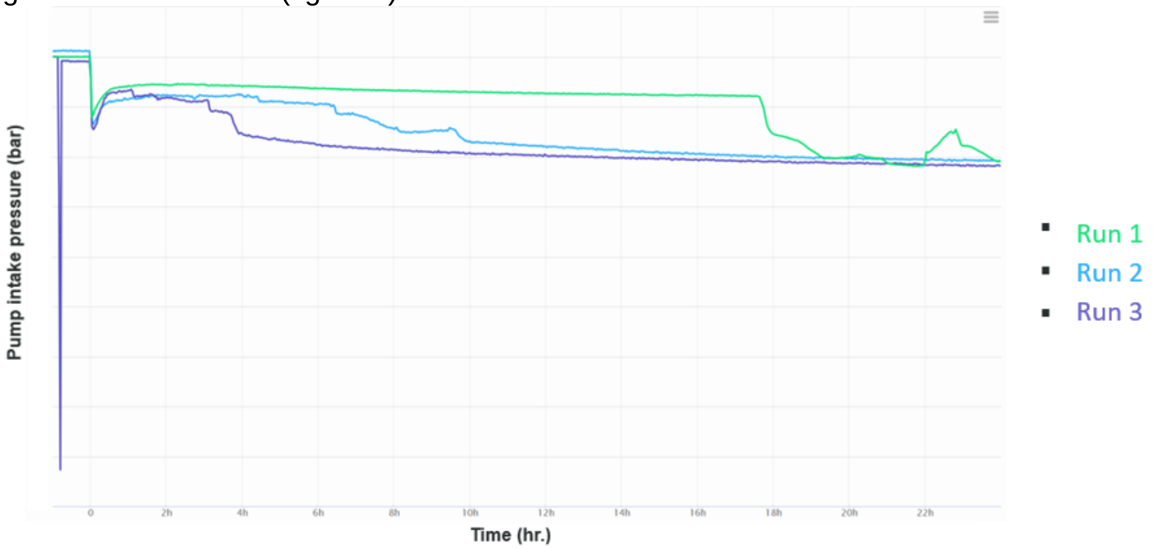


Fig. 3: Startup profiles of different runs.

- Detection of stage wear, scale accumulation, solids plugging, fluids recirculation and productivity index changes (figure 4). This helps identify if the well requires a lower total dynamic head (TDH) to produce similar flow rates compared to previous runs.


Fig. 4: Productivity index tracking.

- Recommendation of proactive chemical treatments for scale and other organic solids (figure 5). 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 approach to ESP failure (Tandazo et al. 2022), (Octaviano et al. 2022).

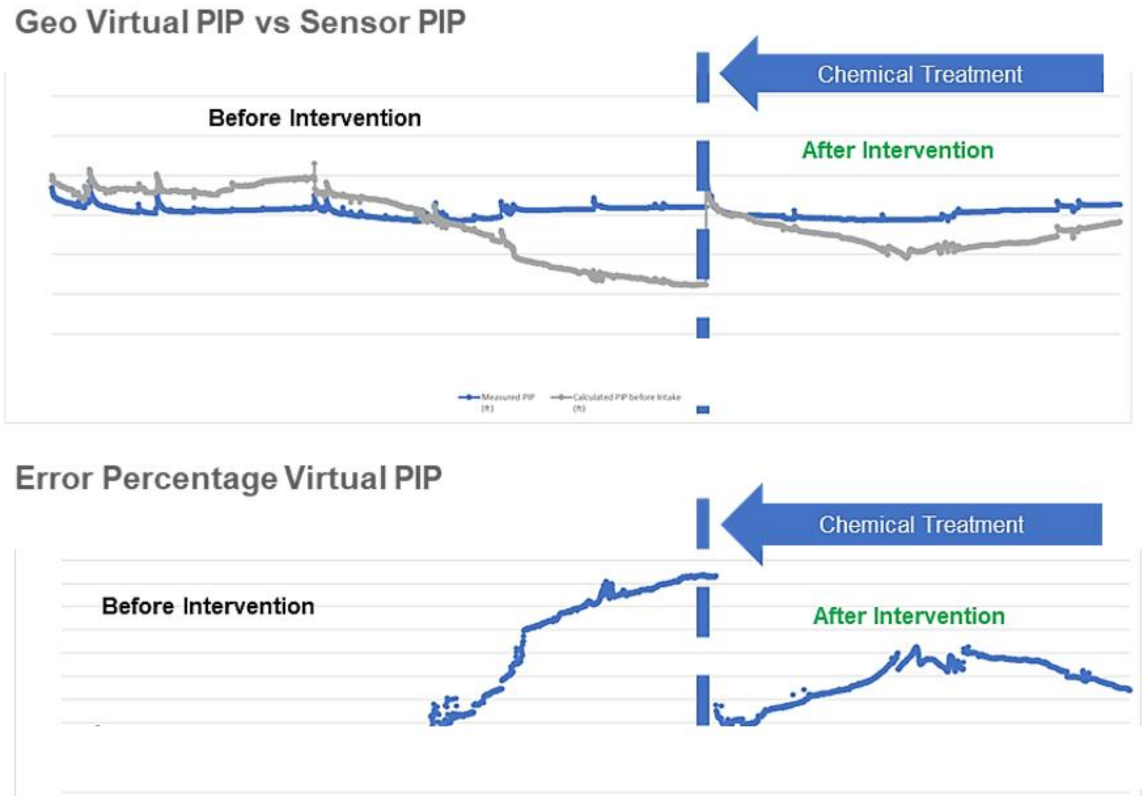


Fig. 5: Proactive chemical treatment based on virtual parameters observations.

### 3.2. Geo virtual temperatures

The motor winding temperature and the fluid temperature are also predicted with less than 3% error (less than 2.5 °C), even during frequency reduction events as seen by the overlapping curves in Figure 6.

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 motor housing 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.


Fig. 6: Geo virtual temperatures tracking.

### 3.3. Geo 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%. 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.

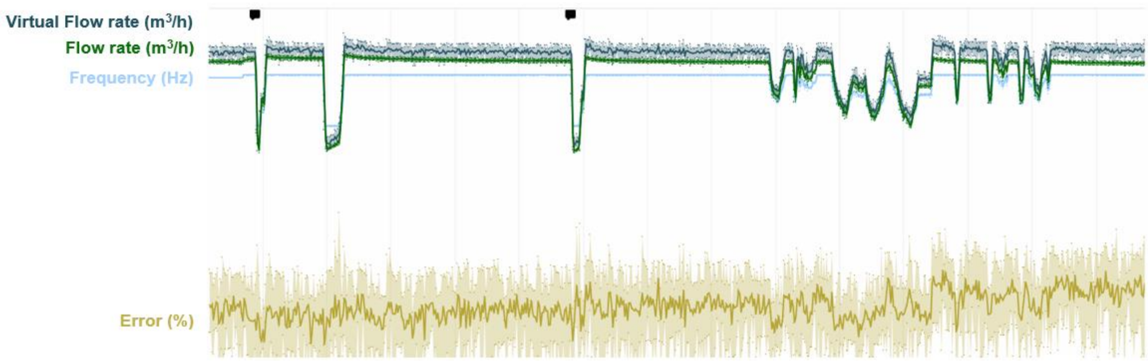


Fig. 7: Geo virtual temperatures tracking.

### 3.4. Geo 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 (Takács 2021), as well as the produced TDH based on the installed high-flow pump. The TDH tracking has several applications in geothermal well monitoring:

- Identification of scale deposition on surface lines. In the following figure, 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.

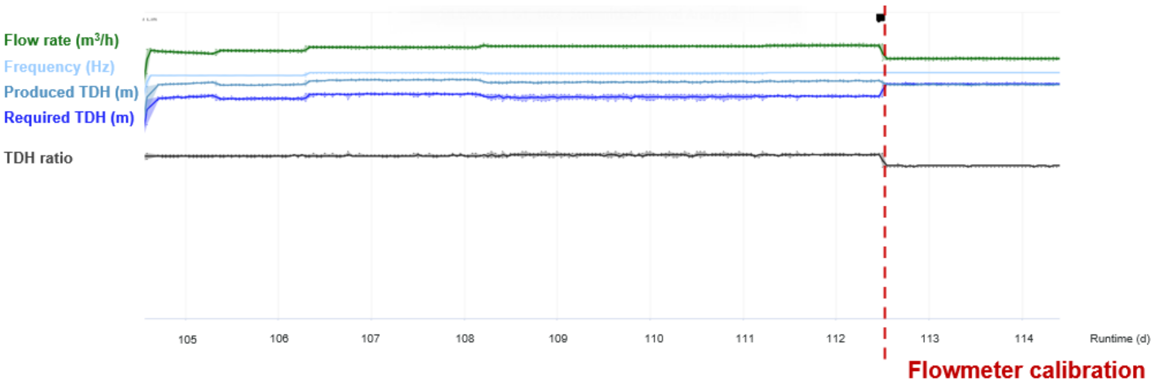


Fig. 8: Required and produced total dynamic head tracking.

- Recognition of scale development or solids plugging at the GeoIntake™. While running at a constant frequency, the flow rate dropped, and the PIP increased. Additionally, vibration doubled and the produced TDH to required TDH ratio decreased. 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 at the GeoIntake™.

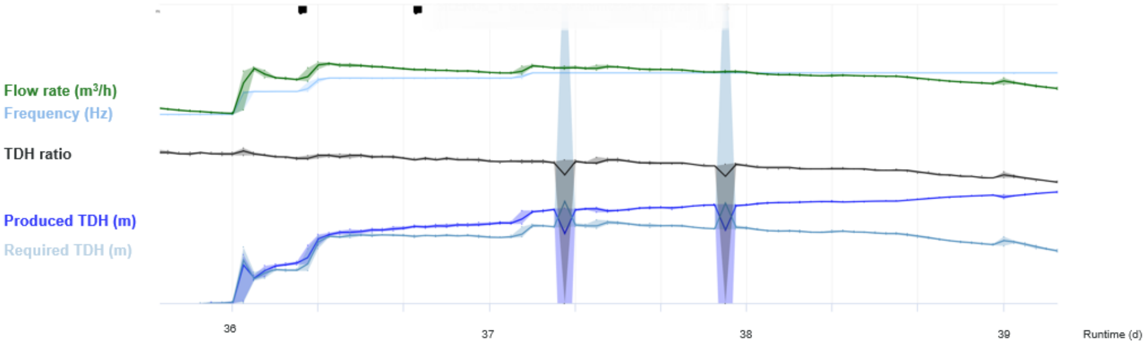


Fig. 9: Scale build-up detection at the GeoIntake™.

### 3.5. 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 has a highly oscillatory nature, 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™ 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.

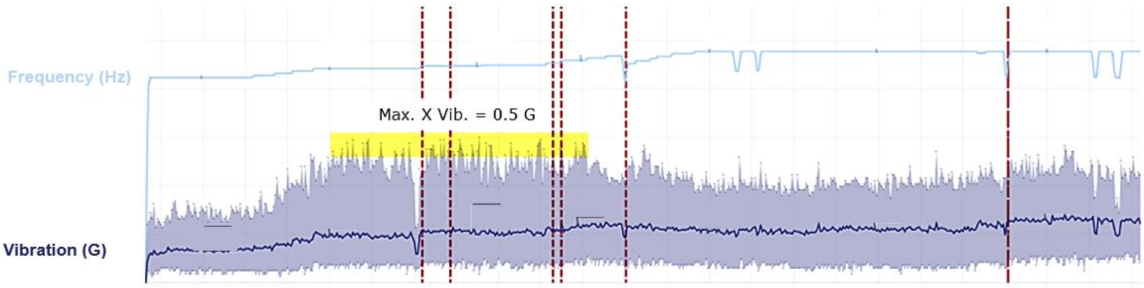


Fig. 10: Vibration resonance.

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

### 3.6. 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. 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 (Williams and Shipp 2019), (Gonski 2012), (Ye and Wilcox 2018). 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 favourable for a longer motor run life.

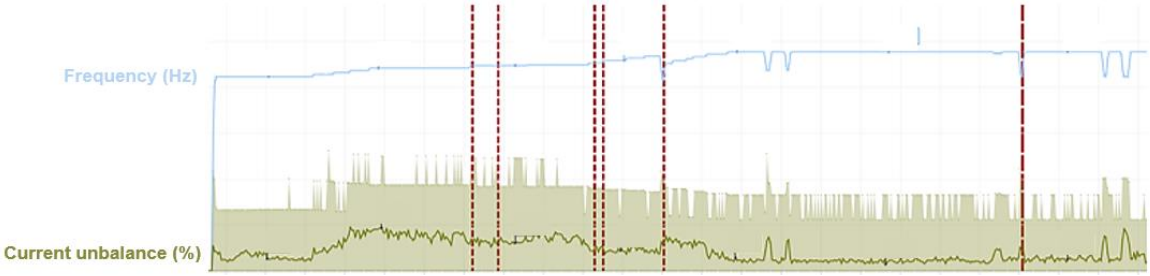


Fig. 11: A-phase current unbalance tracking during resonance frequencies.

### 3.7. Operation dashboards

To improve the daily review of the geothermal system, the following indicators have been implemented:

- Performance: this key performance indicator (KPI) includes a description of events as a status bar, operation time and empty spaces in the data transmission.

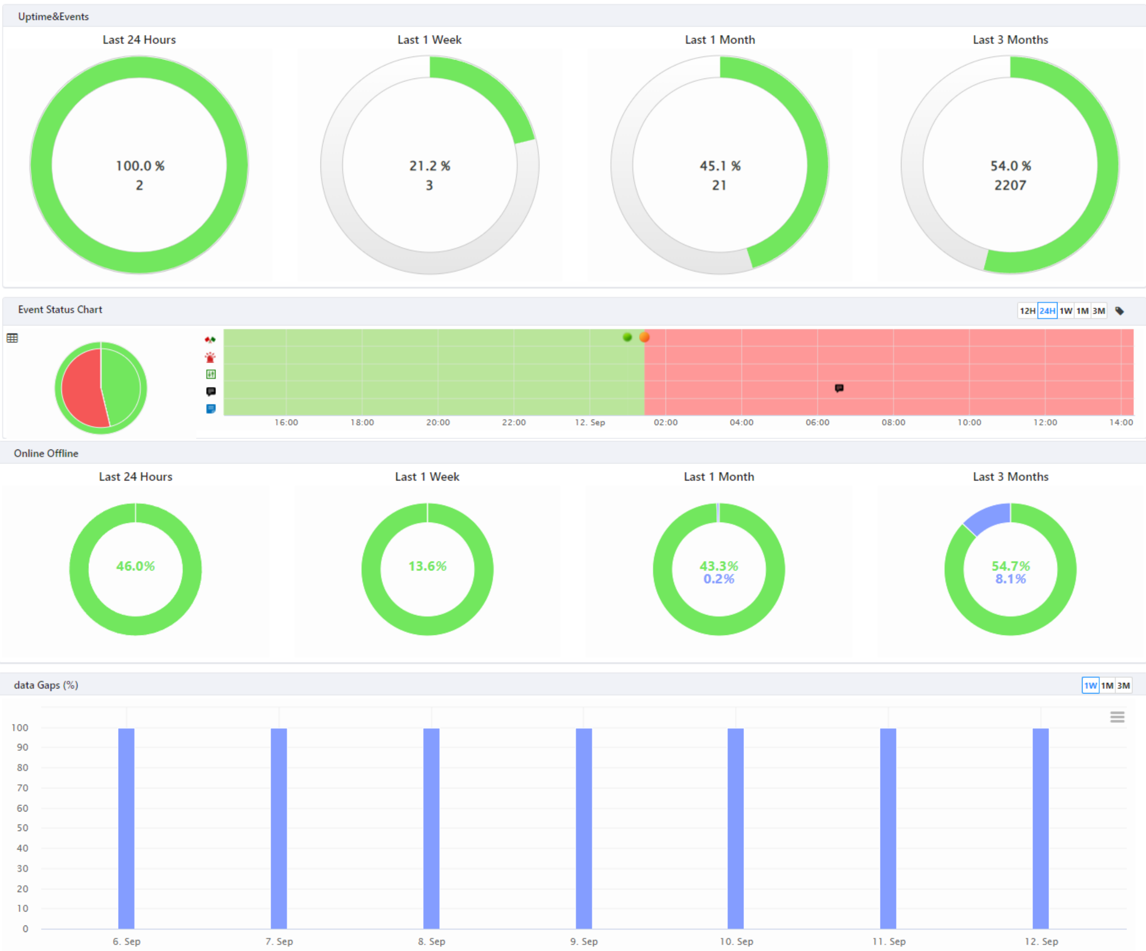


Fig. 12: uptime and events summary KPI.

- Operational indices: allow quick identification of the current state of critical operating variables according to predetermined limits.

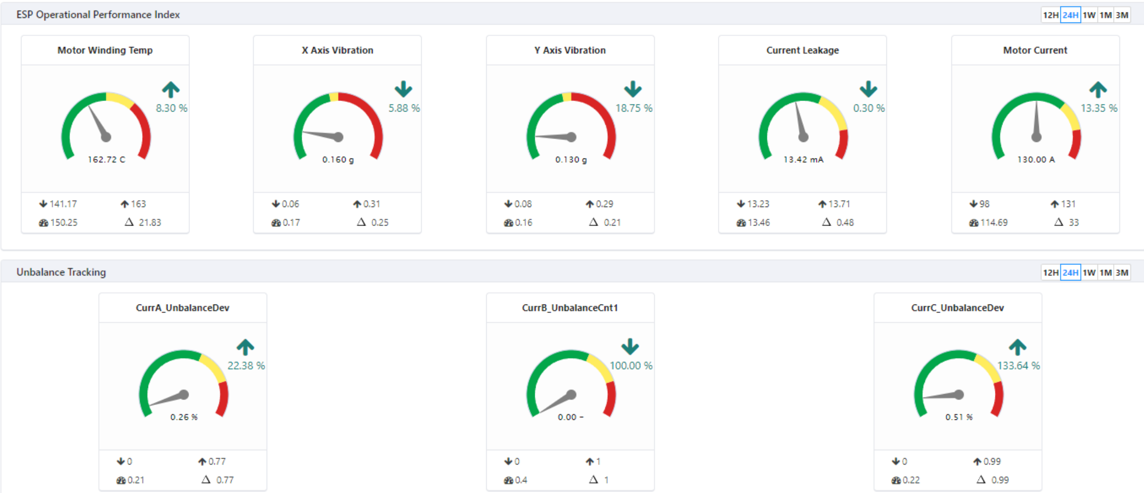


Fig. 13: Critical parameters KPI.

- Power consumption: historical track of energy consumption normalized by obtained production data and required total dynamic head. This feature allows the comparison of energy usage across different applications designs (Lutz 1997).

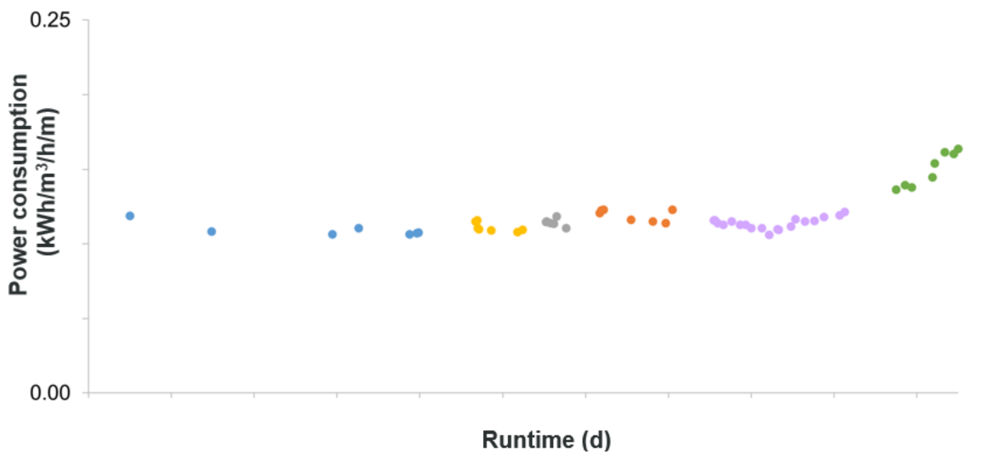


Fig. 14: Normalized power consumption KPI.

## 4. Conclusion

The predicted virtual parameters using machine learning models are within 3% error for pressures, temperatures and 5% for 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®.

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