OPTIMIZING ELECTRICAL SUBMERSIBLE PUMP OPERATIONS WITH AI/ML-DRIVEN REAL-TIME EVENT DETECTION SYSTEMS

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Abstract

In the realm of artificial lift systems, the monitoring and optimization of Electrical Submersible Pumps (ESPs) are paramount due to the high costs associated with unintended shutdowns and failures. Traditional methods, ranging from simple logic-based local alarms to sophisticated 24/7 surveillance centers, have shown tangible improvements in ESP operation. However, scaling such surveillance systems across large asset fleets cost-effectively remains a significant challenge.

Recent advancements focus on integrating real-time automated event detection engines with Artificial Intelligence/Machine Learning (AI/ML) capabilities to address this challenge. These systems process downhole, surface, and electrical sensor data to identify potentially harmful patterns without requiring human intervention. Unlike traditional multi-level threshold alarms, these engines adapt to each other well, minimizing manual fine-tuning and effectively managing the large volume of notifications and alarms generated by evolving operational strategies and well conditions. The robust design of these engines ensures they are noise-tolerant and capable of differentiating between various sensor failures and harmful ESP conditions, thus reducing false alarms.

Also, to tackle the ESP operational challenges, a novel solution has been developed regarding surface measurement devices to infer specific downhole parameters, paired with a calculation engine. This system monitors and processes high-speed motor drive data during ESP operation, alongside transformer readings (3-Phase Voltage and current measurements). A capture and processing module transduces and transmits this data to a hyper-converged edge controller, which performs various functions to yield results in the frequency domain instead of the time domain.

The synergy of AI/ML, high resolution electrical analysis, and real-time data facilitated intelligent actions in digital field operations. This included detecting and ranking operational events, generating focused lists of potential failure threats, and providing actionable insights. Consequently, the number of ESPs needing to be shut down annually was significantly reduced, highlighting the potential of digital transformation in optimizing ESP operations.

Introduction

In a field operated with ESP pumps, it is essential to maintain a meticulous routine in analyzing and interpreting the electrical and dynamic parameters of the downhole sensor in the pursuit of optimizing production and extending the lifespan of the pumps. In this way, the work of the surveillance team is crucial in achieving the following objectives:

Figure 1. Potential benefits of ESP wells Surveillance System.

Therefore, when faced with a certain amount of information associated with alarms, low productivity, and risk of failure, among others, the use of artificial intelligence as an aid in this challenging task becomes essential for the surveillance team to focus on delivering excellence in all the objectives described above. In the case we will detail below, it can be observed that the artificial intelligence system, analyzing all the pump parameters in real time, was able to correctly identify a situation of production loss in relation to the pump's potential.

Adding to the use of an automatic event identification system related to the pump, also describe below another methodology for analyzing the electrical integrity of the frequency converter (VFD) and the ESP pump motor. This is a technique known as ESA – Electrical Signature Analysis, where through high-resolution data capture, it is possible to derive all the electrical calculations. Among others, these include current and voltage harmonic rates, phase diagram for analyzing the balance and integrity of the electrical system, torque/slip/power factor calculated directly in relation to the load operated by the motor, among other key parameters for a detailed analysis of the real-time behavior of the ESP pump.

Background

The operation of Electrical Submersible Pumps (ESPs) in artificial lift systems presents several challenges related to design, commissioning, performance optimization, maintenance, and failure prediction. Given that only 15% of operators rely on a single artificial lift method throughout a well's lifecycle, ESPs are often deployed as the initial artificial lift system, capable of handling production rates between 1,500 and 2,700 BPD.

One of the primary difficulties in maintaining ESP wells is the limited availability and quality of data, with downhole measurements often being sporadic, incomplete, or fragmented across multiple acquisition systems. Additionally, Variable Speed Drives (VSDs), which regulate ESP motor functions, are primarily designed for real-time control rather than comprehensive system analysis, limiting their usefulness for diagnostics and failure prediction.

The dynamic nature of unconventional oil wells adds another layer of complexity, as operators frequently transition between multiple artificial lift methods throughout a well’s lifecycle. While 36% of operators install ESPs initially to maximize production in the first year, operational constraints and inadequate response time to failures often lead to reduced efficiency and unplanned production losses.

Another critical issue is ESP surveillance and event detection. While operators rely on alarm-based monitoring and real-time data analytics, the increasing volume of notifications and threshold alarms can overwhelm operational teams, leading to delayed responses and increased downtime. Moreover, well complexity, including additional completion components such as safety valves, inflow control devices, and bypass systems, further complicates data integration and interpretation. System architecture limitations, such as sensor telemetry, SCADA configurations, and communication infrastructure (wireless, satellite, and cellular networks), also impact real-time monitoring capabilities.

Operational constraints and evolving well conditions require continuous optimization, and the inability to quickly address ESP performance issues can lead to significant production losses.

To address these challenges, a comprehensive data acquisition and synchronization approach is essential for improving ESP well management. The integration of advanced data acquisition systems significantly enhances ESP surveillance by providing high-resolution insights into motor state variables, including torque, true shaft speed, and vibration analysis. These capabilities enable real-time optimization, predictive maintenance, and improved failure analysis, reducing unplanned downtime and operational costs.

Enhancing data accuracy, real-time event detection, and system-wide visibility can significantly reduce unplanned downtime, improve failure prediction, and optimize performance over time.

Methodology

The design of the Automated Event Detection (AED) system is graphically summarized in Figure 2. The AED engine is a compiled code application highly optimized for both edge and cloud deployments. It consists of four major components - data quality (DQ) engine, reference engine, events detectors, and event identification layer. DQ engine checks the quality of the streaming data and raises appropriate data quality flags or gauge failure events. Next, the sensitized data goes through the reference engine which estimates the “normal” operating conditions and creates a “reference” level for each signal.

The reference engine also generates useful features such as noise information, presence of slugging, pump on/off status, and many more. These features are then used by downstream event detectors that contain ML models for detecting unique patterns corresponding to various ESP events. Outputs of the event detectors are then evaluated in the event identification layer and appropriate event flag(s) is raised to the user. The engine is fine-tuned and improved through a feedback loop and standardized testing and reporting workflows. Subsequent sections of this paper discuss important aspects of the AED engine with primary focus on system design and strategic aspects. Readers can refer to Chong et all (2023)

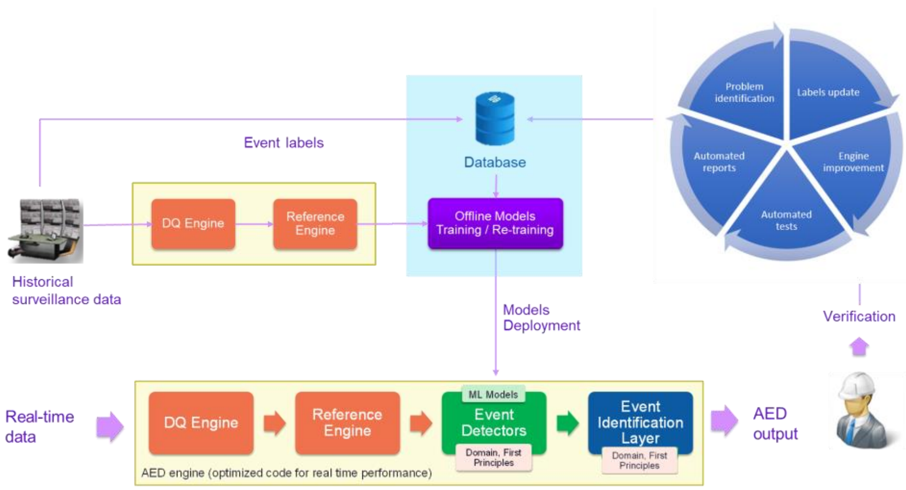

Figure 2. Automated Event Detection (AED) system.

High-resolution electrical measurement acquisitions provide some insight into motor and pump operation. They can be used in the context of dynamic tracking filters designed as observers for system state variables or for parameter estimation. In steady state they can also be used for frequency domain analysis. This shows the impact of three categories of related power or current frequency contents related to motor speed, motor damage and load oscillation. In the real world there are further contents defined by noise, nonlinearities and nonidealities, that lead to various artifacts. Some low frequency tones in the spectrum are related to pump or motor health. As a result, a pattern of related tones can be observed in the spectrum and evaluated. The other tones are related to noise. The fundamental challenge in diagnosis is to detect when artifacts related to degradation rise above the noise floor.

Figure 3 shows the position of the electrical sensors and how this relates to the electrical and mechanical subsystems. The next sections show processed results from facility and field operations, and their interpretation.

The drive performance can already be assessed quite well by the voltage and current measurements. The current response is impacted by a mixture of the drive, line filter, cable, and motor parameters. Analysis and diagnostics can be performed in many ways in a steady or transient state. The principles are based on checking the consistency of input-output relations of subsystems or by propagating the acquired measurements as inputs to models of connected subsystems.

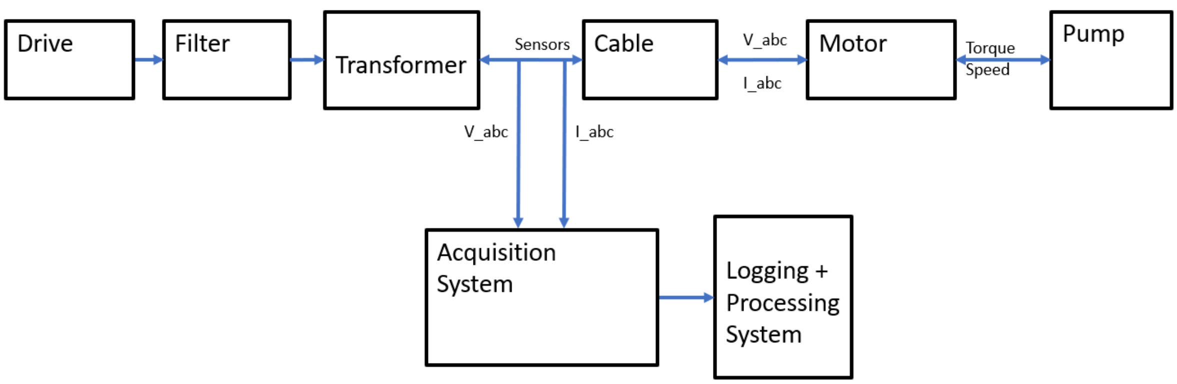

Figure 3. Position of the electrical sensors and how this relates to the electrical and mechanical subsystems in ESP drives.

Results and Value

The deployment of the technologies explained above has yielded significant results, leveraged in the data analysis and new insights delivered, allowing for real-time and historical data evaluation, enabling experts to diagnose health equipment, system integrity, and well conditions.

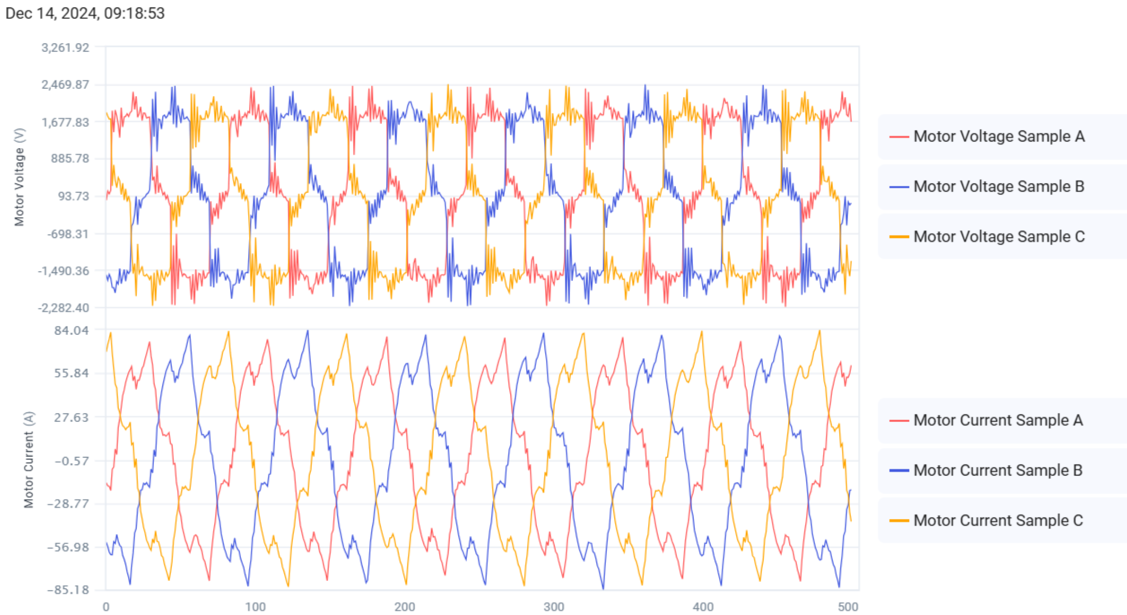

Figure 4. Distortion in Voltage Waveforms.

Let's consider a distortion in voltage waveforms as shown in the figure 4.The analysis allows us to identify optimized operational conditions with balanced voltage and current phases, while also highlighting issues such as high Total Harmonic Distortion (THD) levels, which could affect motor winding integrity and cause overheating and vibration. The findings emphasized the importance of monitoring THD, evaluating VFD performance, and have provided valuable insights into the electrical and mechanical behavior of the ESP systems, guiding proactive measures to enhance equipment longevity and operational efficiency, showing numerous benefits, The electrical signature analysis implemented for ESP operations has shown innumerous benefits among the following:

- Correlate operational and electrical parameters for each well condition, such as synchronous frequency changes and THD, to identify optimized operation points that enhance the Remaining Useful Life (RUL).
- Provides access to new live data for identifying harmonic filtering malfunctions, which could cause motor winding and insulation problems, increasing the Risk of Failure (RoF).
- Identifies mechanical or electrical stress over the motor-pump system due to fluid ratio changes in the well or presence of solids, potentially increasing RoF.
- Ensures high performance by diagnosing critical events accurately, minimizing false alarms, and preventing unplanned shutdowns.
- Easily identify current and voltage balance, as well as shaft rotational direction, to detect any potential issues impacting motor integrity.
- Detects single or multipoint energy leakage, including asymmetry to earth and phase impedance issues, preventing voltage groundings and current imbalances that significantly increase RoF.

- Enables engineering analysis for better ESP power efficiency and lower motor slip, contributing to increased RUL.
- Combined with Dismantle, Inspection and Failure Analysis (DIFA), offers detailed insights into electrical damage over the pump, identifies KPOs for damage estimation magnitudes, and provides valuable insights for future identifications of events that increase RoF.
- Identifies electrical events during start-up, leading to improved operational practices and reduced excessive electrical stress on the motor and entire electrical system, thereby enhancing RUL.

Let's consider another well and explore the parameters associated with System Efficiency as shown in Figure 5.

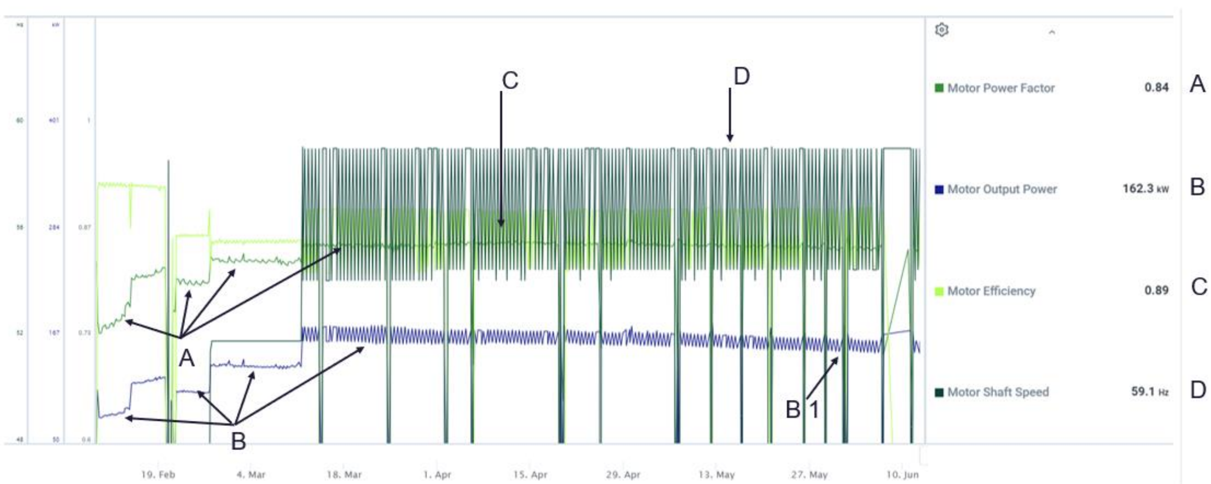

Figure 5. Drive System Efficiency Main Indicators.

A) The motor power factor increased during the frequency ramp-up, attributable to the motor operating at a higher load. This improvement reflects a better ratio relative to motor size, thereby enhancing the overall efficiency of the electrical system.

B) As expected, the motor power increased in response to higher frequency and voltage levels, aligning with its optimal operating point relative to size. However, in accordance with the expected decrease in current over time, the power has also shown a declining trend.

C) The system efficiency oscillated between 0.86 and 0.89 due to variations in shaft speed. Generally, higher efficiency was observed when the shaft speed closely matched the Variable Frequency Drive (VFD) frequency.

D) An oscillation in shaft speed, ranging from 59 to 55 Hz, was observed, particularly at a frequency value of 60 Hz. A possible cause could be associated with resonance in the mechanical system connected to the motor. However, this oscillation showed no correlation with Total Harmonic Distortion (THD) or shaft stability.

In summary, this technology offers non-intrusive, 24/7 monitoring and well prioritization, acting as a trusted assistant for engineers, helping to optimize operations and extending equipment life without compromising safety. The system accurately diagnoses potential issues with minimal false alarms, preventing unplanned shutdowns and shifting maintenance from reactive to preventive, thus increasing equipment life. The technology provides real-time metrics for performance and energy efficiency analysis, optimizing operations and reducing energy consumption as shown in Figure 6.

These technologies are versatile and compatible with any brand of VFD, controller, and downhole motor, whether onshore or offshore, with Ethernet, Satellite, or Cellular connectivity, and features a high-performance IIoT device integrating with a digital platform using AI analytics for low-flow event detection, enhancing capabilities and providing valuable insights that help reduce the Risk of Failure and increase Remaining Run Life. Artificial Intelligence accurately identified deviations from normal conditions, providing timely alerts for effective response and issue mitigation. The combination of these systems offers significant cost savings by detecting anomalies, prioritizing wells in real-time with high accuracy, and allowing operators to take early actions to extend the life of ESP Motors, reduce downtime, and decrease workover frequency.

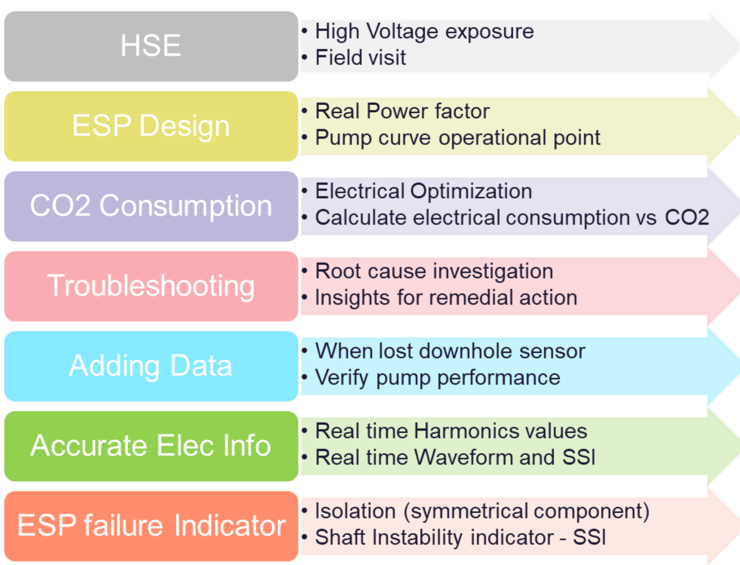

Figure 6. ESP Power Analyzer key benefits.

Conclusions

The outcome of this real-world example underscores the importance of using dedicated artificial intelligence to monitor ESP data in real-time. Such visibility is crucial for enabling the operations team to make informed, timely decisions. This capability is essential for maintaining the operational continuity of the ESP pump, optimizing production levels, and extending the lifespan of the centrifugal pump. Below are the main goals achieved through the combination of digital oilfields and AI for surveillance activities:

1. **Enhanced Monitoring and Optimization:** The implementation of AI/ML-driven real-time event detection systems has transformed the monitoring of ESPs, allowing for continuous analysis of electrical and dynamic parameters. This leads to improved production optimization and extended pump lifespan.

2. **Proactive Maintenance:** The use of Electrical Signature Analysis (ESA) and high-resolution data capture enables the identification of potential issues before they escalate, shifting maintenance practices from reactive to preventive. This proactive approach significantly reduces unplanned downtime and operational costs.

3. **Data Integration Challenges:** The need for comprehensive data synchronization is critical to enhance surveillance and improve failure prediction.

4. **Reduction of False Alarms:** The automated event detection (AED) systems are designed to minimize false alarms by accurately distinguishing between normal operational variations and actual failures, thus improving response times and operational efficiency.

5. **Cost Savings and Efficiency:** By detecting anomalies and prioritizing wells in real-time, these technologies provide substantial cost savings, reduce workover frequency, and enhance overall operational performance.

6. **Future Implications:** The findings suggest that the continued evolution of AI/ML technologies in ESP operations will lead to further improvements in equipment longevity, energy efficiency, and overall system reliability, paving the way for more sustainable practices in the oil and gas industry.

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