ADVANCED VARIABLE FREQUENCY DRIVE CONRTROL: OPTIMIZATION AGAINST INCOMPLETE FILLAGE

Biplav Chapagain – DV8 Energy
Tim Hinojosa – Occidental Petroleum

ABSTRACT

Incomplete fillage conditions where the downhole pump does not completely fill up with incompressible liquid has been widely accepted to have detrimental effects on pumping efficiency and moreover the equipment longevity in sucker rod pumping applications. Methods of synchronizing the pump displacement to the wells inflow and thus reducing incomplete fillage has been of keen interest to the industry. During operation, surface sensors are used to monitor polished rod load and position to obtain a surface load vs position graph. Concurrently, a pump load versus position graph is generated by solving the 3-D wave equation for deviated wells in the diagnostic mode. Pump fillage is computationally detected with a mathematical algorithm that accurately estimates the traveling valve close (TVC), standing valve open (SVO), standing valve close (SVC) and traveling valve open (TVO) points in the pump dynamometer card. A sophisticated pump off control (POC) algorithm called Advanced Fillage Mode (AFM) with a continuous feedback mechanism is then implemented to significantly reduce incomplete fillage pumping cycles using a variable frequency drive (VFD) for speed control. AFM accepts the pump fillage set point, maximum SPM, and the minimum SPM as the three operational parameters. AFM continuously monitors the pump fillage, compares the pump fillage on each stroke to the fillage set point and dynamically adjusts the SPM of the well to maintain pump fillage near the fillage setpoint. This synchronizes pump displacement to the inflow of the well. Additionally, various versions of AFM are available depending on the tolerance for incomplete fillage. In pumped-off or near pumped-off situations, the tolerance for incomplete fillage is very low. Whereas, in cases with fluid level above the pump where incomplete fillage manifests itself as gas interference, one may have a higher tolerance for incomplete fillage to pump the fluid to the surface. A calculated “Fluid Level Above Pump” (FLAP) parameter is available where a user may select the FLAP threshold for controller bias. AFM is an intelligent algorithm that determines its key pump off control parameters such as the rate of SPM increments, rate of SPM decrements, observation cycles and stoppage time automatically. Additionally, AFM uses a continuous feedback strategy to continuously optimize the operational variables based on the well’s performance. We will present several before and after case studies to demonstrate the advantages of using AFM

INTRODUCTION

Variable frequency drives have had multiple case studies performed throughout the industry and have been proven to be effective in reducing failure frequencies, and in some cases increasing production. With the introduction of new devices to work with these VFDs, along with IoT technology, a user can now do well surveillance and make more analytical assumptions with a higher degree of precision with the increased amount of data that is available and stored for the operator to evaluate. The ability to capture each stroke along with the performance indicators assists the operator’s decision to operate a well in a more optimized state.

BACKGROUND

For this pilot we did a comparative analysis with conventional VFD control where a pump fillage target set by the user along with a minimum and maximum strokes per minute, against an advanced fillage mode and a calculated fluid level control method. An edge device was installed in addition the to VFD to capture each dynamometer card, along with the performance indicators associated with each card able to be accessed by the user. Utilizing the data captured for each stroke, the algorithm assisted in accomplishing the targets set forth by the user. The edge device along with the algorithm was deployed for the three methods of control: traditional VFD control, advanced fillage mode, and a calculated fluid level control to compare the advantages and disadvantage of each method, along with testing the functionality of each control method so the user can select their preference based on their objective for the selected well.

FIELD TRIALS

TRADITIONAL VFD CONTROL

Traditional VFD control accepts the pump fillage set point, maximum SPM, and the minimum SPM as the three operational parameters. AFM continuously monitors the pump fillage, compares the pump fillage on each stroke to the fillage set point and adjusts the SPM of the well to maintain pump fillage above the fillage setpoint. This synchronizes the pump’s displacement to the inflow of the well. AFM is an intelligent algorithm that determines its key pump off control parameters such as the rate of SPM increments (step size for speed up), rate of SPM decrements (step size for slow down), observation cycles (cycles observed before making a decision) and stoppage time (time pumped off) automatically. Additionally, AFM uses continuous feedback loop based strategy to continuously optimize the operational variables based on the performance of the well.

The wells selected for this pilot had a VFD installed and running with traditional VFD control method over the past few years. A time was set up to gather data while doing quality control checks to ensure accurate data was captured since each dynamometer card was being captured and stored. This process continued for two weeks before deploying the advanced VFD control methods. During the data capture, performance trends were analyzed and the users noted improvements that could be implemented to align with their pumping philosophy with the data that was being captured that was not apparent when analyzing this subset of wells through the existing host SCADA system. The granularity of capturing every stroke provided valuable insight to the operator with a plan forward to implement and guide the control of the well going forward.

ADVANCED FILLAGE MODE

Advanced Fillage Mode (AFM) is a sophisticated pump-off control (POC) algorithm which uses the pump fillage as its primary operational parameter. AFM uses surface sensors to monitor the polished rod load and position to obtain a surface dynamometer card. Downhole dynamometer card is calculated by solving the wave equation in the diagnostic mode and is plotted as a pump load versus position graph. Pump fillage is subsequently calculated using an advanced algorithm based on the estimated traveling valve and standing valve opening and closing points. Pump fillage is continuously monitored and strongly correlates to the well inflow. The AFM algorithm can be modified to operate with various pumping philosophies that may be desirable to the users. 'Maximum Production' version of AFM is biased towards maximizing production while being more tolerant towards incomplete fillage strokes. This version may speed up the well relatively aggressively when the pump fillage exceeds the fillage target. Whereas, when the pump fillage does not meet the fillage target, the SPM decrement is minor to negate the loss of production.

After monitoring the pilot wells for a period, advanced fillage mode was deployed to the wells to optimize the pump fillage settings by allowing the algorithm to assist in adjusting the VFD parameters by analyzing key performance indicators and dynamometer cards. Soon after the deployment of AFM, improvements were noticed in the amount of pump fillage in the dynamometer cards, along with a tightened operating range of minimum and maximum strokes per minute. Figure 1 depicts the improvement in pump fillage with this control method being implemented by an average of 5% increase. An analysis was performed on the dynamometer cards to track the improvement in optimizing incomplete fillage to help extend run life.

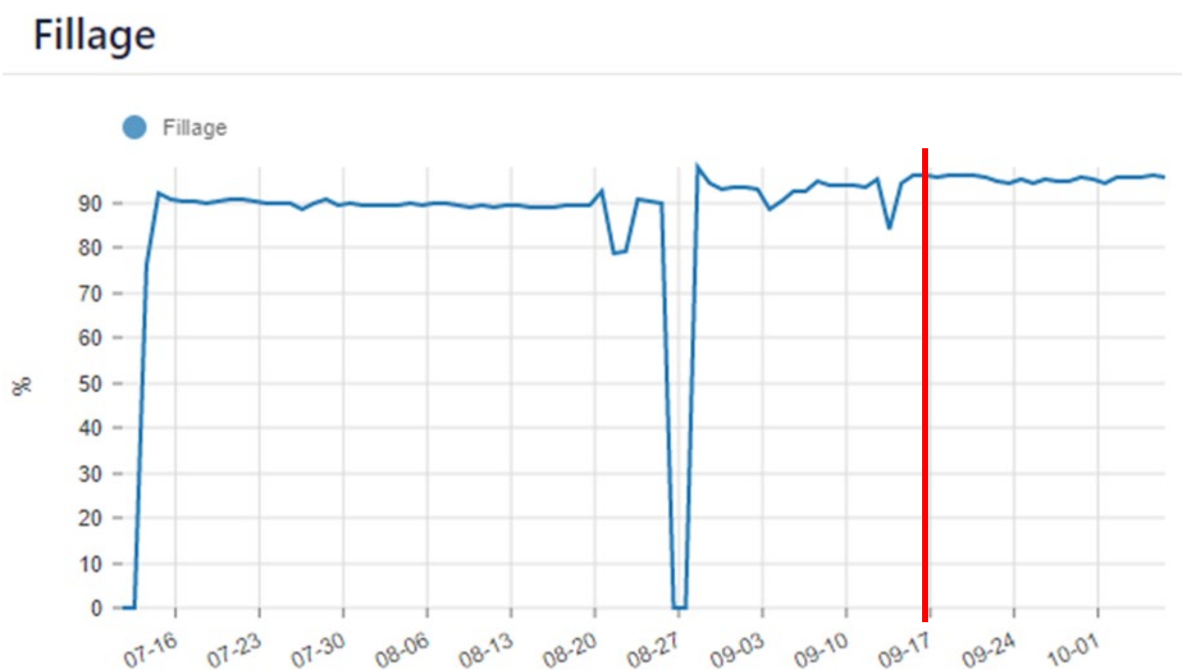

Figure 1 – Pump fillage improvement after deploying AFM

Figure 2 highlights a drastic improvement in the reduction of cards most notable in low fillage strokes and low fillage strokes with dynamometer cards below 85%. The driving force behind the improvement was the ability to have every stroke captured in the cloud-based system available for both the operator and the algorithm to learn the behavior of a given well to allow for better optimization strategies in the future. To highlight the advantage of capturing data from every stroke, it is evident in Figure 3 that optimization of the VFD was needed by analyzing the correlation of pump fillage and strokes per minute before AFM was deployed. It can be observed on the high resolution time series data that pump fillage often drops below 93% fillage target. Following, large and quick reductions in SPM as a response. The dynamic of these drastic speed changes is very hard on the downhole equipment. The advantage of having the high-resolution data is this may have continued to go undiagnosed as the trends from the host SCADA system did not reflect what the device was capturing since the data is being polled much less frequently. After AFM was deployed, a noticeable improvement was made in both pump fillage and strokes per minute being more uniform pictured in Figure 4. It can be observed from Figure 4 that the AFM algorithm was able to optimize the speed decrements and increments to maintain a higher pump fillage without sacrificing production. The same philosophy was able to translate to the other 2 wells in this pilot where an improvement in the number of incomplete fillage strokes is depicted in Figure 5 and Figure 6.

	Before AFM	**After AFM**
Total Strokes	13773	12550
Fillage SetPoint	94%	94%
Fillage used for Comparison	93%	93%
Number of low Fillage Strokes.	5046 (36.36%)	2655 (21.2%)
Number of lower Fillage Strokes (<85%)	3602(26.2%)	495 (3.9%)

Figure 2 – Comparative fillage analysis in traditional VFD control versus AFM

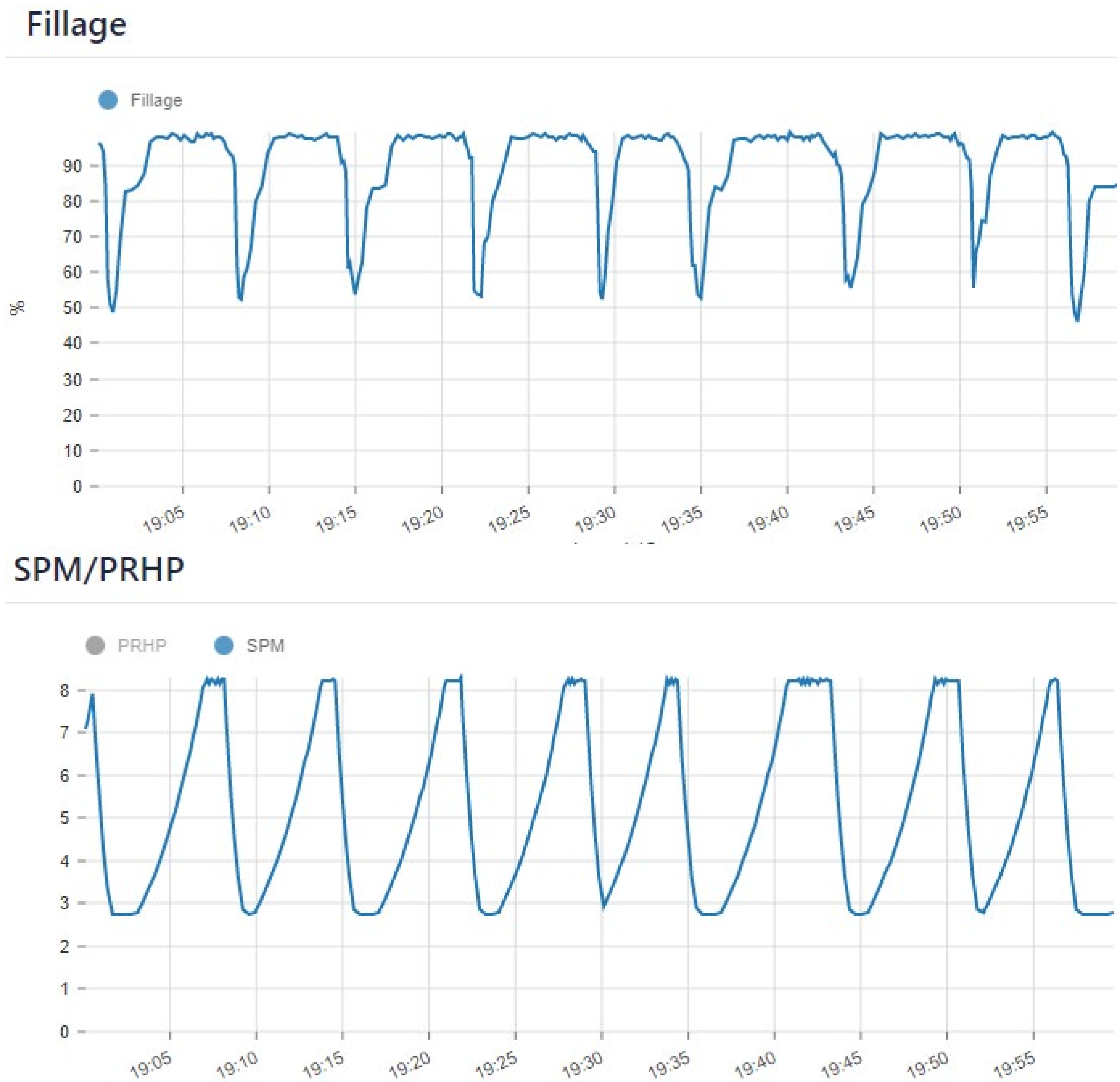

Figure 3 – Pump fillage and SPM before AFM deployment

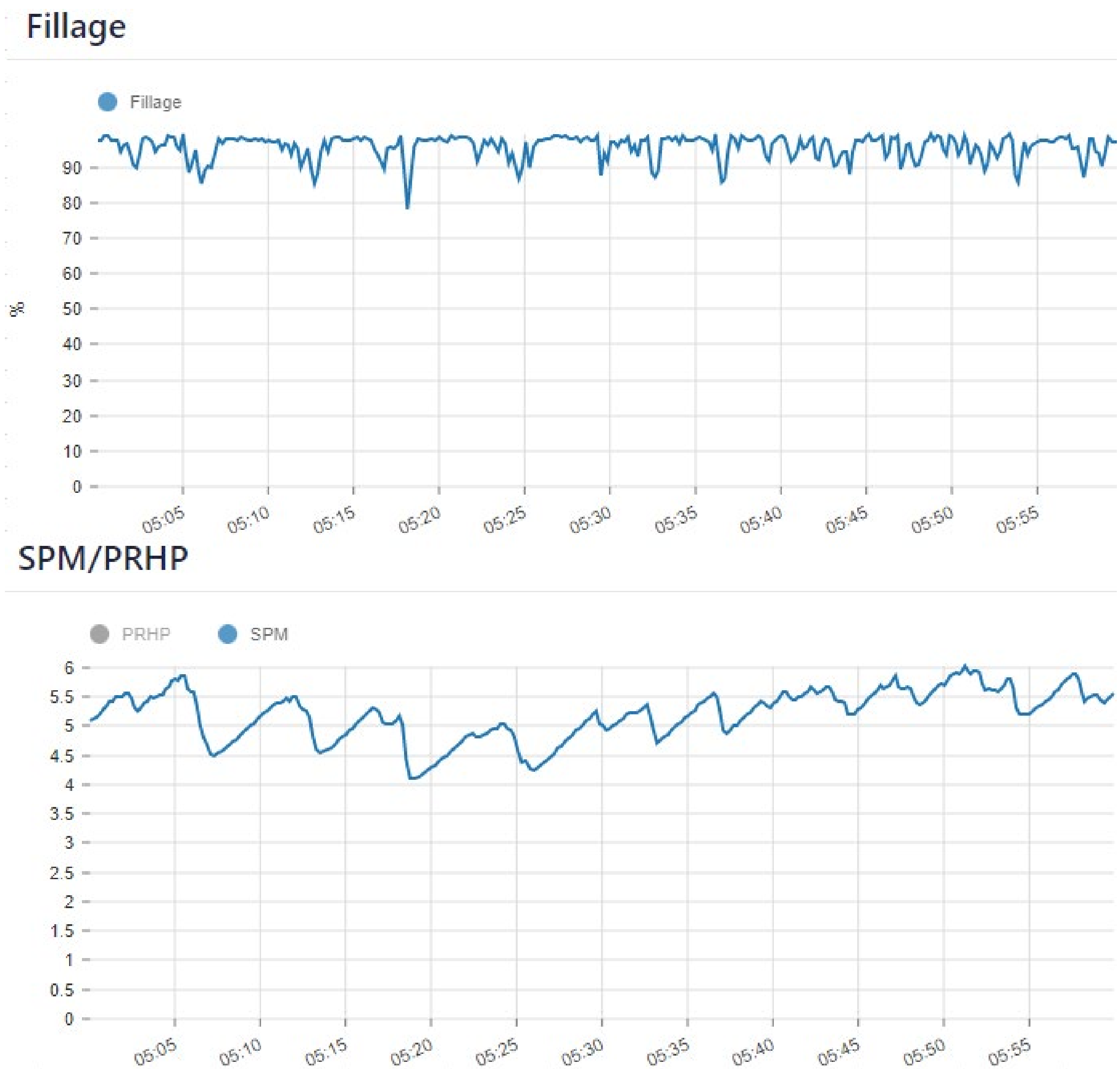

Figure 4 – Pump fillage and SPM improvements after AFM deployment

	Before AFM	After AFM
Total Strokes	14311	14251
Fillage SetPoint	90%	90%
Fillage used for Comparison	89%	89%
Number of low Fillage Strokes.	8245 (57.6%)	748 (5.2%)
Number of lower Fillage Strokes (<80%)	688 (4.8%)	1 (0%)

Figure 5 – Additional comparative analysis between AFM and traditional VFD control

	Before AFM	After AFM
Total Strokes	9981	9487
Fillage SetPoint	94%	94%
Fillage used for Comparison	93%	93%
Number of low Fillage Strokes.	9964 (99.8%)	1842(19.4%)
Number of lower Fillage Strokes (<90%)	6691 (67%)	120 (1.3%)

Figure 6 – Additional comparative analysis between AFM and traditional VFD control

CALCULATED FLUID LEVEL CONTROL

The FLAP mode algorithm operates with a key operational parameter FLAP (Fluid Level Above Pump). The incomplete fillage observed when the fluid level is high above the pump and the upstroke load line is much below the F0Max line is due to gas interference [1]. Decreasing the pump displacement does not have significant improvements in the pump efficiency. However, in pumped-off or close to pumped-off conditions where the fluid level is close to the pump, incomplete fillage is due to the lack of fluid from the inflow and often manifests itself as the more detrimental fluid pound or choked pump [1]. In this case, where the fluid annulus is close to the pump, reducing pump displacement has been observed to reduce incomplete fillage and synchronize the pump displacement to the inflow. Hence, FLAP mode is designed to operate in different control modes based on the high-resolution fluid level estimations above the pump. In FLAP mode, the FLAP (Fluid Level Above Pump) parameter is selected by the user. When the fluid level rises higher than twice the FLAP setpoint, the well is pumped at the maximum SPM prescribed by the user until the fluid annulus declines. When the fluid level is above the FLAP point but less than twice the FLAP setpoint, the "Maximum Production" flavor of AFM is assumed. Whereas, when the fluid level falls below the FLAP setpoint, “Maximum Fillage” flavor of AFM is in effect.

An ideal candidate for this control method would be a well where gas interference is evident in the downhole dynamometer cards. Traditional VFD control as well as AFM both struggle from being able to differentiate between incomplete fillage due to gas interference and incomplete fillage in near pumped off conditions where fluid pound and choked pump are possibilities. Both control methods initiate speed changes once a portion of the dynamometer card is measured lower than the pump fillage target regardless of the diagnosis of fluid pound or gas interference. Operating under FLAP control method allows the VFD to continue drawing down the calculated pump intake pressure to a control point determined by the operator. An advantage, as mentioned above would be capture the production left behind due to gas interference while understanding the amount of incomplete fillage seen in the cards would likely be greater than the operator would typically see for a given well. An example of being able to draw down the calculated pump intake pressure is pictured in Figure 7. While operating in traditional VFD mode and AFM we see a higher calculated pump intake pressure. Once FLAP mode was deployed, we see an immediate decrease in the calculated pump intake pressure. Well tests for the well were executed so that the operator could determine this control method would be the method going forward by assessing the economic gains from the amount of oil produced to help better understand the risks versus reward from operating in this mode. One of the initial concerns from operating in this mode was related to the increased number of incomplete fillage strokes as one may expect to see due to gas interference. Throughout the operation of this well in FLAP mode, it is seen in Figure 8 that pump fillage did not suffer to the degree that was initially expected, and in fact appeared to be in line with the previous control modes. To further justify continuing operating in FLAP mode it must provide an economic benefit to outweigh the risks associated with increasing the amount of incomplete pump fillage, which is commonly known to have detrimental effects on the downhole equipment. Figure 9 shows from an inferred production plot that it appears with the drawdown of the calculated pump intake pressure, produced fluids also increased. Another consideration while operating in this mode is to understand strokes per minute in most cases will increase to reach the calculated fluid above pump target set by the user. This is an important metric to consider for those interested in taking polished rod velocity into account for their pumping philosophy. In Figure 10 we see an increase in strokes per minute, but nothing concerning as the trial continued. We also see a sharper increase in strokes per minute as the calculated fluid level target was decreased to attain maximum production. The increases in production were also validated by well tests performed at the production facility. Although this method of control is relatively new, the results produced from the pilot have been promising. The results have also been replicated in the other 2 wells this method of control was deployed on.

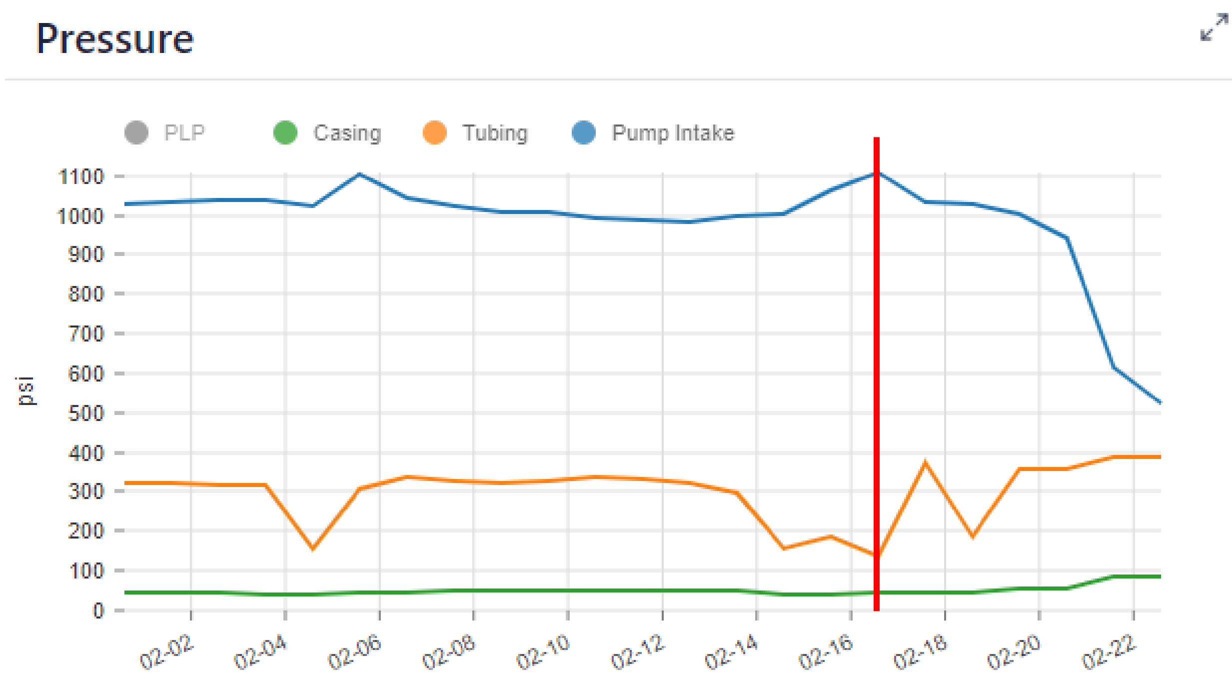

Figure 7 - Decrease in calculated PIP in FLAP control mode

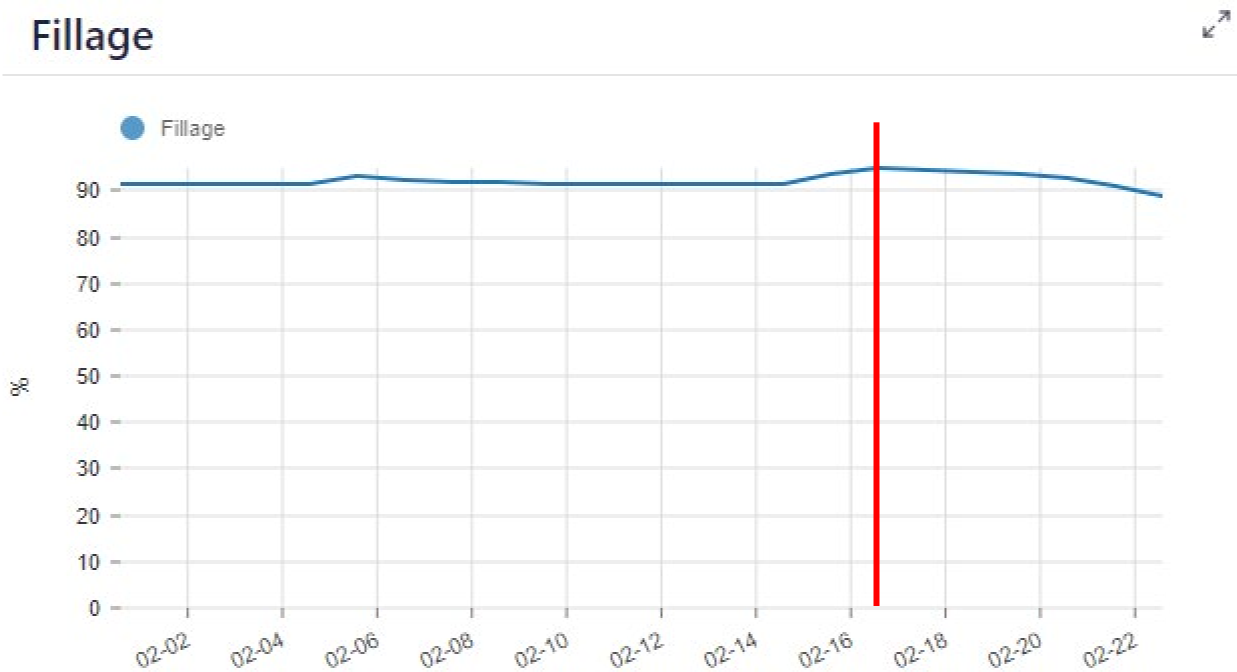

Figure 8 - Pump fillage in FLAP mode

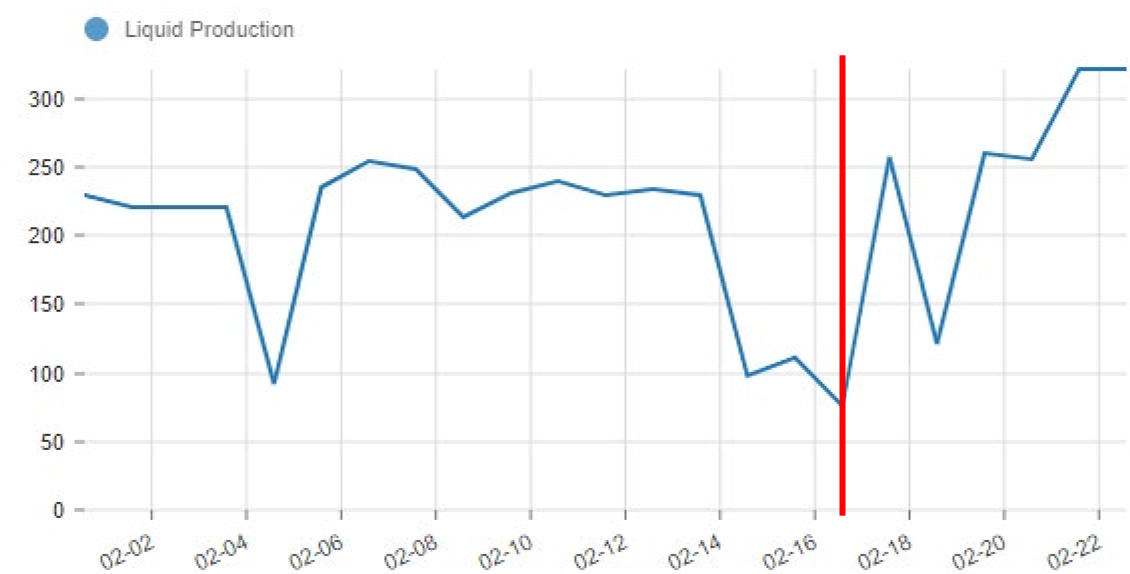

Figure 9 - Increased liquid production in FLAP mode

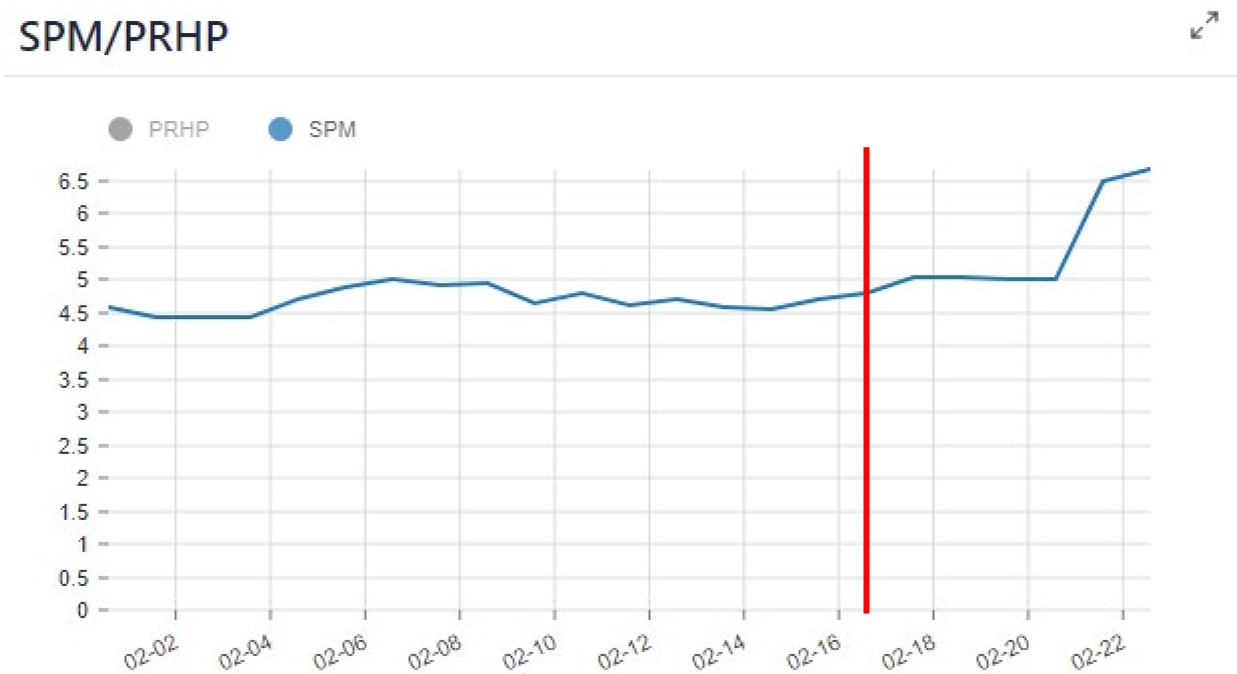

Figure 10 - Increase in strokes per minute in FLAP mode

CONCLUSIONS

Implementing other methods of VFD control, coupled with the high frequency data captured from the edge device has shown drastic improvements from both an operational standpoint, along with time management for the operators responsible with the surveillance of the well. As time goes on the operator also has the flexibility to switch between the different control modes outlined above. Although each control mode offers its advantages, it does not come without caveats. The operator will need to establish which set of criteria is needed for each individual well based on an economic standpoint balanced with the pumping philosophy in place. The benefit of having the algorithm autonomously make fine-tuned adjustments from the feedback loop, it is still foundational that an operator still evaluates the data to ensure the VFD is performing in an optimized state. The value added from the edge devices allows the user to also manage their time and focus their attention on wells that are deviating from their normal state.

REFERENCES

[1] McCoy JN, Rowlan OL, Podio AL. The Three Causes of Incomplete Pump Fillage and How to diagnose them correctly from Dynamometer and Fluid Level Surveys, SWPSC, Lubbock, Texas (2010).