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Advance ESP Failure Detection by Fuzzy Logic

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Abstract. Electric Submersible Pump (ESP) is the most widely used artificial lift (AL) equipment across Sumatera Light Operation (SLO). At a time, ESP experiences failures due to different causes which impact its efficiency. ESP early pump-failure detection is a crucial step to minimize LPO. In the current fluctuating or even low oil price environment, executing the wells with pump efficiency issues becomes one of the economic jobs to optimize the production level. Challenges for this option are: how fast petroleum engineer can detect early pump failure symptoms? How many resources will be allocated for the daily review of a total 2,480 producers in SLO? The previous ESP failure detection tool has been established based on manual data feeding and hard cut-off criteria to generate an "exception signal". Unfortunately, there were many ESPs which have longer ESP failure detection time that continuously sliding. In several cases, the wells are already down due to late being captured as pump failure. There is an opportunity to develop a more real-time/online data processing and analysis using artificial intelligence (AI) approach. This project has been developed with a more robust and more parameter integration, such as fluid test data, ampere data, fluid level, wellhead pressure and other supporting data, like job history. Fuzzy logic is implemented to assess the degree of potential pump failure. Online surveillance from SCADA is utilized to improve the data quantity and data quality on the fuzzy logic tool to be more like petroleum engineers for decision-making in ESP failure detection. The result of this project is presented as Fuzzy Confidence Index (FCI), in which the highest value of FCI correspondents to a higher potential of pump failure. ESP early failure detection output is broadcasted daily through "Integrated Exception Management Signals" (IEMS), providing daily potential pump failure wells to petroleum engineers for further process.

Keyword(s): Electric Submersible Pump (ESP), ESP failure detection, fuzzy logic, artificial intelligence, loss production opportunity (LPO), proactive job

1 Introduction

The oil price downturn brings a huge downside to the financial health of all oil & gas companies. Higher production decline as the impact of reducing economic jobs becomes a serious issue, especially if there are no more drilling activities due to less economic potential. The only way to secure production is optimization at existing wells. A proactive routine service job at ESP failure well is potentially the next prioritized job which compensates the impact of production reduction or minimizes the downside due to no drilling activity and less major WO job in SLO. However, the existing tool that captures the well failure due to ESP efficiency issues is still far from the expectation. This condition worsens after fewer engineers review ESP failure symptoms daily for all 2,480 ESP wells, and some of them will be retired soon. Unreliable tools and less dedicated engineers are the main reason for higher production decline rate at many wells which have longer ESP failure detection. Moreover, some of producers were down/off due to late to be captured and followed-up for proactive ESP change job. In this case, there is significant hidden oil loss from low pump efficiency that expected to be recovered soon before the wells go down and become actual oil loss.

An advanced ESP failure detection tool is preferred to be developed to address all root causes for having faster ESP failure detection with less engineer's intervention. The project team utilizes fuzzy logic to develop the tool, like a petroleum engineer, for decision-making in ESP failure detection. This method is based on an expert system which captures all knowledge from subject matter expert (SME), including senior petroleum engineers who will be retired soon. The result of this tool is presented as "Fuzzy Confidence Index" (FCI) representing the potential ESP wells in failure/under efficiency issue condition.

2 Literature Review

Different perspectives by each of petroleum engineer to decide failure tendency bring difficulties to achieve the objective of this project, especially in determining the exact terms of "slightly decline", "a production fell a bit", "small drop" or any qualitative review by all engineers. Zadeh, L.A. (1996) described fuzzy logic with "computing with words", that is not literally the words are used for computing by the computer, but that words need to be translated into mathematical representation by utilizing fuzzy set. In fuzzy set, the words that need to be converted are known as "linguistic variables". Zadeh, L.A., Klir, G. J., & Yuan, B (Eds). (1996) created a book about the concept of fuzzy sets, fuzzy Logic, and fuzzy systems. Later, Mamdani's method is utilized for developing "Fuzzy Inference System" (FIS). By understanding the advantages of fuzzy logic to solve the main problem, project teams developed "Advance ESP failure identification" tool that delivers a daily prioritization well list with ESP failure tendency.

3 Methodology

Fuzzy logic is a multi-valued logic derived from fuzzy set theory which deals with reasoning that is approximate rather than precise. It imitates humans to make decisions based on imprecise and non-numerical information. Furthermore, fuzzy logic is capable of capturing and interpreting data or information vagueness like age, temperature, etc., which deal with linguistic and subjectivism. Fuzzy logic can do modelling of imprecise dependencies based on rules from human expertise and do parallel computation using words/rules with different of strengths. To solve the problem in this project, fuzzy logic was implemented to assess the degree of potential pump failure based on all surveillance data like fluid test data, ampere data, fluid level and well head pressure (as linguistic variables). However, based on advice from the subject matter expert, slope data of all surveillances at all different periods will be selected as data input instead of the percentage drop of its surveillance.

This development process starting with data collecting, data processing, "Fuzzy Inference System" and output prioritization. Furthermore, the output will be reviewed by petroleum engineer for validation and verification. If the output data are not meet the SME's requirement to capture the wells with ESP failure indication, the tool must be improved until meet with the goal. Once validated, the tool proposed for a pilot test to all wells that previously experienced with ESP failure indication. This is to prove whether this tool can detect faster than previous tool. Once no additional issue in utilization and decision quality, "Advance ESP failure identification" tool is ready for full field implementation across SLO.

4 Findings & Argument

This project relies on SMEs since this project plans to transfer SMEs' knowledge to the tool. Based on a forum group discussion with SME, project team needs critical data like fluid test data, ampere data, fluid level, wellhead pressure and other supporting data, like job history. Another important surveillance is ampere online data from SCADA that useful to increase the density of data input for the tool to seek ESP failure symptom. As input from SME, all surveillance data must be processed to find its slope in different period (last 30, 60, 90, 180 days), not percentage drop of its surveillance.

A special step is needed for fluid production test data which must be calculated for data normalization before slope generation. Besides, the fluid production test data is the primary surveillance because compared to other surveillance, the distribution of fluid test data is extensive from 150 – 15,700 BFPD. Moreover, the slope of all surveillances needs to be normalized for having same scale from 0 to 1. The slope normalization starts from defining the angle of the slope then normalized it to be in the range of 0 – 1 by simply using formula in the equation below.

$$slope\ normalization = \frac{2\ x\ \tan^{-1}(slope)}{\pi} \quad (1)$$

Fuzzification is one of the next processes under FIS to map each of crisp value (numeric value) into fuzzy set to get degree of membership by using membership function for all linguistic variables. "Triangular Cut" membership function is selected which not only for helping the petroleum engineer to decide the wells with ESP failure/ESP efficiency issue and prioritize all the wells with negative slopes by their degree of membership data. Based on input from the expertise and to save computational time and burden, the project team only used two membership functions for normalized slop to represent linguistic value of "downtrend" and "uptrend". All slope normalization data will be processed based on fuzzy set theory, so all data not in fuzzy value must be changed to fuzzy value through "fuzzification," which is represented by degrees of membership. The degree of membership represents the truth values in fuzzy logic which have intervals [0, 1]. Based on statistical data in SLO, the slope normalization for historical well failure which ended-up with reactive RS job shows that the range of slope normalization is between -0.05 and 0.05.

In the fuzzy processing/inference step, the project team must conduct the discussion/interview with all SMEs to develop fuzzy rules that drive this tool's logic. All knowledge and experience, including best practices and lesson-learned from SMEs, must be translated into the fuzzy rule.

Table 1. Fuzzy Rules

Rule#	BFPD	AMP	FAP	WHP	FT
1	Downtrend	Downtrend	Downtrend	Downtrend	High
2	Downtrend	Downtrend	Downtrend	Uptrend	High
3	Downtrend	Downtrend	Uptrend	Downtrend	High
4	Downtrend	Downtrend	Uptrend	Uptrend	High
5	Downtrend	Uptrend	Downtrend	Downtrend	High
6	Downtrend	Uptrend	Downtrend	Uptrend	High
7	Downtrend	Uptrend	Uptrend	Downtrend	High
8	Downtrend	Uptrend	Uptrend	Uptrend	High
9	Uptrend	Downtrend	Downtrend	Downtrend	Low
10	Uptrend	Downtrend	Downtrend	Uptrend	Low
11	Uptrend	Downtrend	Uptrend	Downtrend	Low
12	Uptrend	Downtrend	Uptrend	Uptrend	Low
13	Uptrend	Uptrend	Downtrend	Downtrend	Low
14	Uptrend	Uptrend	Downtrend	Uptrend	Low
15	Uptrend	Uptrend	Uptrend	Downtrend	Low
16	Uptrend	Uptrend	Uptrend	Uptrend	Low

Once the fuzzy rule is set, the system will check which rules comply with every ESP well based on the fuzzy data of each surveillance. After that, the next process is "implication" to get the output from the "if-then" rule (antecedents – consequents) with fuzzy logic operation on each complied rule. The fuzzy logic operation that implemented to connect all antecedents for this project is fuzzy operation intersection which utilized "and" operator. This operator will select the minimum antecedent truth as the output in implication process. Then, do "clipping" or "alpha-cut" for consequent membership function at the level of selected minimum antecedent truth. All clipped membership functions from all the rule consequents need to be combined into single fuzzy set by doing "aggregation" to determine the final output. Refer to Mamdani's method, the operation that utilized for the aggression is "or" which follow with "max" function.

The end of fuzzy inference process is defuzzification. In defuzzification, the input is the aggregate output from "aggregation" process which represented with the area on clipped membership functions from all the rule consequents. All the rules that developed by the experts are evaluated based on its fuzziness, while the final output from fuzzy system must be a crisp data and it is a single number, that called in this project with "Fuzzy Confidence Index" (FCI). FCI represent the confidential level of each well in ESP failure tendency. In Mamdani-style fuzzy inference, centroid technique, or center of area (COA) will be utilized for this project to calculate the FCI.

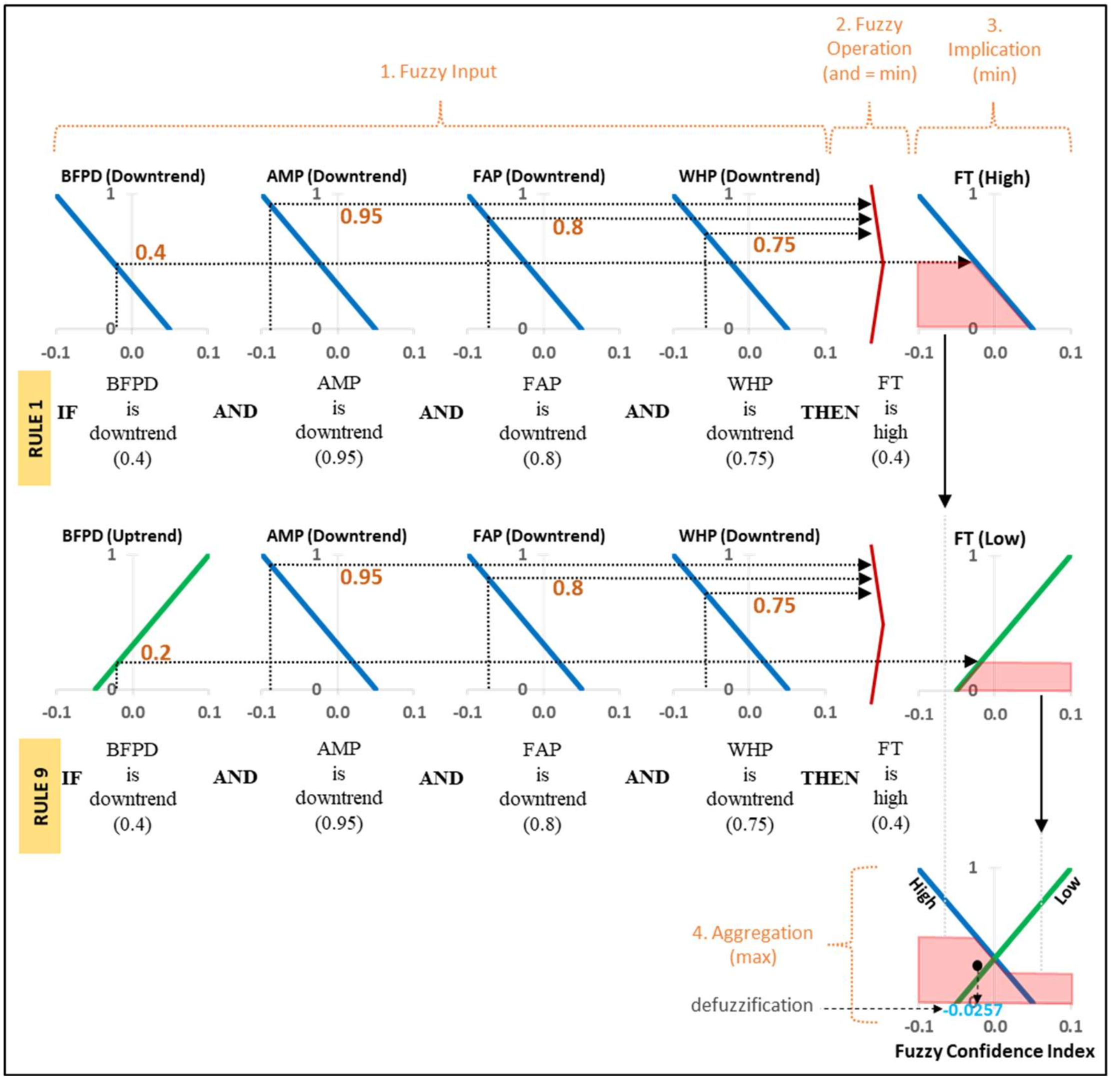

Figure 1. Fuzzy Inference System

All FCI data in different data group will be compared at each well and selected only one FCI data which have maximum FCI value. Based on the expert's input, the well with all four FCI data in positive value will be excluded. Once the lowest negative FCI value selected then the system will take the absolute value to be compared among wells. Higher absolute FCI value, higher tendency of ESP failure wells. Then, final FCI data (absolute FCI value) will be daily broadcasted through the major review system that called with "Integrated Exception Management Signal" (IEMS). IEMS will update the FCI data list automatically by running the fuzzy logic algorithm of "Advance ESP Failure Identification" tool. Once FCI data is updated, exception signals (code: WALIFT50) will appear, waiting for the petroleum engineer to review and follow up for the further process.

Table 2. Example of FCI Data List

RANK	WELL NAME	FCI 30	FCI 60	FCI 90	FCI 180	ABS_FCI
1	BLS-152	-0.344879	-0.344879	-0.344879	-0.344879	0.344879
2	ANT-006	-0.000383	-0.268026	-0.268026	-0.268026	0.268026
3	BLS-375	-0.250845	-0.250845	-0.250845	-0.250845	0.250845
4	AMP-022	-0.226990	-0.226990	-0.226990	-0.226990	0.226990
5	BLS-179	-0.186600	-0.186600	-0.186600	-0.186600	0.186600
	.					
	.					
	.					
2442	MIN-001	0.002245	0.063554	0.068315	0.068315	no failure tendency
2443	BNK-009	0.000843	0.070384	0.070384	0.070384	no failure tendency
2444	BLS-341	0.072959	0.072959	0.072959	0.072959	no failure tendency
2445	STO-029	0.074918	0.018664	0.004257	0.002796	no failure tendency
2446	BKS-548	0.001066	0.000428	0.000394	0.075639	no failure tendency

Before full field implementation, this tool must be validated and conduct pilot test to all wells that previously experienced with longer ESP failure detection in 2019. The result is promising that "Advance ESP Failure Detection can improve ESP failure detection time by 90% from 75.3 to 7.3 days.

5 Conclusions

After 12 months of implementation, 1,309 ESP wells were captured under exception signals (WALIFT050). However, only 24% need follow-up to conduct proactive ESP recondition jobs. Some signals that do not require follow-up were mainly due to the ESP performance still running in at optimum range. Based on several reviews and consultations with the PE advisor and AI advisor, the first step to improve this issue is to increase the FCI's cut-off captured by IEMS. If there is no significant improvement, the project team must fine-tune the fuzzy logic model. S-curve data of the keep-as-is (KAI) exception signal (during 12 months of implementation) shows that the new FCI cut-off in 90% distribution is 0.02. This new cut-off significantly increases the percentage of followed-up signals from 24% to 64 %.

By implementing the new cut-off, 485 ESP wells are captured by this tool and need follow-up for proactive routine service jobs. No wells were down due to low pump efficiency issues as the first reason. Based on actual data from the start failure date until the exception signal date, SLO ESP failure detection time was reduced significantly by 90% (median data). The ESP failure wells captured by the new tool have faster detection and significant improvement in production deliverability. This acceleration positively impacts the company, successfully securing the production improvement by 511 MBO, or equal to $ 43.4MM.

6 References

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