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Ocean Economy and Fault Diagnosis of Electric Submersible Pump applied in Floating platform☆

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Abstract

Ocean economy plays a crucial role in the strengthening maritime safety industry and in the welfare of human beings. Electric Submersible Pumps (ESP) have been widely used in floating platforms on the sea to provide oil for machines. However, the ESP fault may lead to ocean environment pollution, on the other hand, a timely fault diagnosis of ESP can improve the ocean economy. In order to meet the strict regulations of the ocean economy and environmental protection, the fault diagnosis of ESP system has become more and more popular in many countries. The vibration mechanical models of typical faults have been able to successfully diagnose the faults of ESP. And different types of sensors are used to monitor the vibration signal for the signal analysis and fault diagnosis in the ESP system. Meanwhile, physical sensors would increase the fault diagnosis challenge. Nowadays, the method of neural network for the fault diagnosis of ESP has been applied widely, which can diagnose the fault of an electric pump accurately based on the large database. To reduce the number of sensors and to avoid the large database, in this paper, algorithms are designed based on feature extraction to diagnose the fault of the ESP system. Simulation results show that the algorithms can achieve the prospective objectives superbly.

Keywords: Ocean economy; Fault diagnosis; Electric Submersible Pump (ESP); Floating platform; Feature extraction; Current card

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1. Introduction

During past decades, concerns over energy shortages and environmental pollution problems have been growing. A current phenomenon occurring is that more and more researchers pay attention to ESP due to its oil production performance advantages such as high discharge head, convenient management, and Yang (2004) has researched both the features and applications of ESP. Since the fact that the structures of the ESP are more complicated and the working conditions under the shaft are also comparatively odious, the fault rate of ESP is unpredictable during the period of oil production. Many efforts have been paid to deal with the fault problems of ESP. Meanwhile, Liu et al. (2011) proposed the fault diagnosis methods about ESP based on wavelet analysis and Xi (2008) put forward another method based on vibration detection, which has investigated the fault diagnostics of the centrifuge pump by using both data analysis in the spectrometric and discrete wavelet transform method.

It is a basic method based on current cards to diagnose the faults of ESP but it has low efficiency and inevitable human errors will also occur. According to Harihara and Parlos (2012), the pumps fault can be diagnosed by the motor electric signals. Therefore, a mathematical model is established to improve the oilfield development effectiveness after the relationship between ESP wells pressure-out value and time is known through the study of Zheng et al. (2012). The holding pressure diagnosis techniques in the management of submersible electric pump well have been applied in Bohai Q Oil field by Dong (2004). However, if the pressure-out time is too long, the production status and efficiency will be affected, which will aggravate the more serious fault degree of ESP. On the other hand, the macro-control diagram of ESP is helpful to improve the production efficiency of ESP well, and Li et al. (2008, p.121) analyzed the production situation of the wells in each region and discusses the relevant technical measures that should be adopted.

According to Zhao et al. (2006) and Zhang (2008), not only can the fault tree of the ESP can be drawn, but also the minimum cut sets, minimum path sets and structure function were solved after the qualitative and quantitative analysis of ESP faults, which based on the FTA method. Before that, Gan et al. (2002) researched the fault diagnosis and fault prognosis by taking advantage of the FMECA and FTA's information. Besides this, mode analysis and feature extraction from the vibration signals of good and fault conditions were also reported by Sakthive et al. (2010). In addition, Farokhzad (2013) used the technique of Fast Fourier Transform and Adaptive Neuro-Fuzzy Inference System to detect the fault of pumps, and Li et al. (2010) adopt the method of Fuzzy Petri Nets to diagnose the ESP. The theory of fuzzy mathematics and expert data have been used to establish the pattern recognition model of ESP faults, of which drawback is the establishment of the fuzzy relationship matrix has some limitations and uncertainties. In recent years, the method of neural network fault diagnosis has been widely used in ESP to improve the accuracy and quickness of diagnosis, such as Peng (2016) and Wang et al. (2007) diagnosed pumps fault using the neural network. Besides, Wang (2013) and Rajakarunakaran et al. (2008) have detected and diagnosed the faults of pumps systems. According to many researchers, such as both Li (2010) and Zhao (2011) diagnosed the faults based on analyzing the vibration signals. Before that, Leon et al. (2000) researched the parameters of motor. So the approach that vibration signal analysis and feature extraction of electric pump unit and the establishment of the typical fault vibration mechanics model can implement an effective diagnosis of ESP. Besides, Behzad et al. (2004) presented the technique that both vibration analysis and motor current signature analysis (MCSA) can be used for detection of faults and abnormalities in machine systems. In addition to the above methods of faults diagnosis, there are some other comprehensive diagnosis techniques. such as those discussed by Mckee (2015) who detailed the relationship between vibration cavitations sensitivity parameter and centrifugal pumps condition, Zhao (2010) and Feng (2007) researched the state monitoring and fault diagnosis technology and synthetic diagnosis model of ESP respectively.

In this paper, we propose a technique by extracting the features of current cards in different fault modes of ESP to recognize the faults of ESP. We aim to reduce environment pollution, increase the ocean economy and improve the fault diagnosis level. After collecting the common fault's current cards, the features, such as expectation and variance, need to be extracted respectively from different current cards. Besides, a library between current cards and features can be set up on a table and improved gradually. Then, we aim to achieve the intelligence and reduce the human errors of the faults diagnosis methods. In addition, designing the features recognition algorithms and the simulation results show that the method we present above can achieve a certain effect.

2. Electric Submersible Pump(ESP)

2.1. ESP Systematic Component

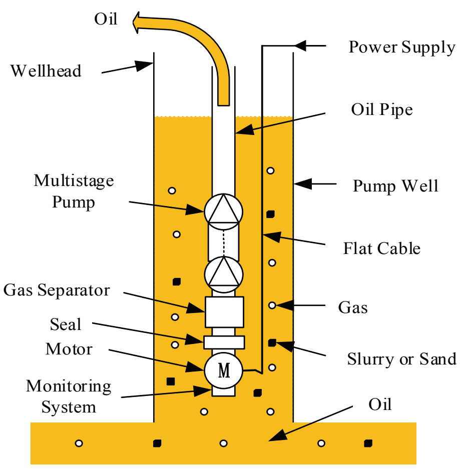

Figure 1: Schematic Diagram of the ESP System

The ESP systematic component is divided into the surface equipment and the downhole system components. The surface equipment (beyond the wellhead) consists of the motor controller, the transform, the junction box and surface cable and basic ESP downhole system components are the multistage pump, the gas separator, the seal section, the motor, the power cable and the monitoring system.

As shown in Figure 1, different components play different roles. The motor drives the multistage pump and seal section while the current is supplied through the power cable from surface equipment. The seal section is located between the pump and motor and transfers the motor torque to the pump shaft. The gas separator takes the place of a standard pump intake and separates a portion of the free gas from the fluid entering the intake to improve pump performance. The pump is a multistage centrifugal pump, which lifts the fluid through the pipe to the surface and the monitoring system can be attached to the bottom of the motor and monitors options including the pump intake pressure and temperature, discharge pressure and temperature, etc.

2.1. ESP Operation Principle

When the motor drives the impeller on the pump shaft rotates at a high speed, the fluid in the impeller is sent to the sides of the impeller along the blade between the flow channels under the action of centrifugal force. Because the liquid is forced by the blades, its pressure and velocity increase at the same time. Under the further action of the impeller, the velocity energy of the liquid is transformed into pressure energy and the liquid flows to the impeller entrance of the next stage pump. After the liquid successively passes through the multistage impellers, the liquid flows onto the ground where the liquid pressure successive increases enable it to overcome the pump discharge pipeline resistance of energy.

Owing to the complicated well environment and uncertain impurities in the well liquid, such as gas, slurry or sand and so on, it is almost impossible for the ESP to run in an ideal condition and the possibility of ESP failure rate will increase. In order to reduce the economic losses and protect the ocean environment, the study on faults diagnosis of ESP is necessary.

3. Fault Detector Design

The flow chart of fault detector can be designed as following figure.

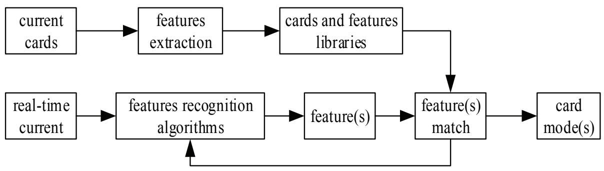

Figure 2: The Schematic Diagram of Fault Detector Design

3.1. Features Extraction

After the collection and study of several faults current cards, extracting the features of each card, such as expectation, variance and so on. The mapping relations between current cards and features is shown in the Table 1 as below.

According to the theory of probability and statistics by Han and Xie (2006) and Zhang (2015), what the expectation reflects is the average of the random variable size. Similarly, variance is often used to measure the deviation or discrete degree between the random variable and its expectation.

Table 1: The mapping relation between current cards and features

Categories of current cards	Change trends of features
Casing gas causes underload shutdown	Uptrend of variance; Periodicity
The gases affect	Variance almost retain the same
Well liquid contain sediment or mechanical impurities	Downtrend of variance
Insufficient liquid supply in oil wells	Downtrend of expectation; Start-up fail again
Insufficient liquid supply and intermittent pumping in oil wells	Downtrend of expectation; Periodicity; Start-up success again
Electric pump impeller wear	Downtrend of expectation;
Motor wear	Uptrend of expectation;
Well liquid contain mud	Uptrend of expectation; Start-up fail again
Electric pump shaft fracture during run-time	Mutation of falling
⋮	⋮

So the expectation and variance of random variables can be described in the following equations:

$$E(X)=\sum_{i=1}^{n} x_i \cdot p_i \tag{1}$$

$$D(X)=\sum_{i=1}^{n} p_i \cdot (x_i-\mu)^2 \tag{2}$$

Where $\mu = E(X)$, x_i represents the value of discrete random variable and p_i represents the probability of discrete random variable.

3.2. Features Recognition Algorithms

Setting the variance threshold and variance lower than the threshold value is line with current fluctuations, otherwise, they are classed as abnormal. Then, according to the features, recognition algorithms are designed in Figure 3,we can know the features of current cards in different fault modes.

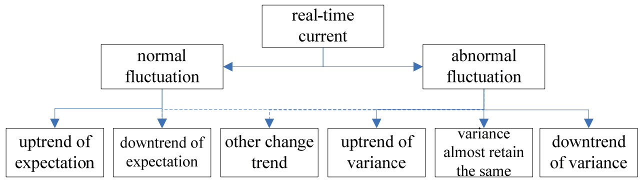

Figure 3: The Schematic Diagram of Features Recognition Algorithms

3.3. Features Match

After the process of features recognition algorithms, matching the features of current card to the mapping relation in the Table 1the card mode can be diagnosed. If not, the algorithm sets and mapping relation need to be further perfected.

4. Simulation Results

In this section, we use MATLAB to simulate the change tendency of the extracted features and the feasibility of the algorithms presented in section 3. As above-mentioned, whether the current normal fluctuates is under the influence of the working condition. Therefore, the simulation results are represented in two cases below.

Case 1: The current is abnormal fluctuations (not include the process of start-up and shutdown). Figure 4 shows the current card of casing gas causes underload shutdown. Figure 5 depicts the variance change trend of the current card, from which we can see the variance has a rising trend with the change of time. So the current abnormal fluctuation is more and more intense, and the working condition can be diagnosed in Table 1.

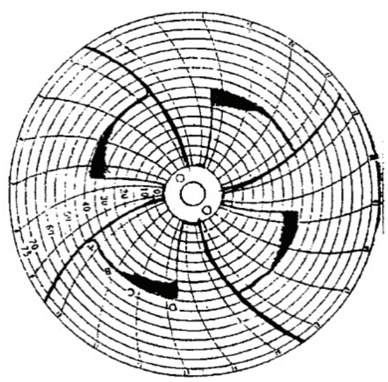

Figure 4: Current Card of Casing Gas Causes Underload Shutdown

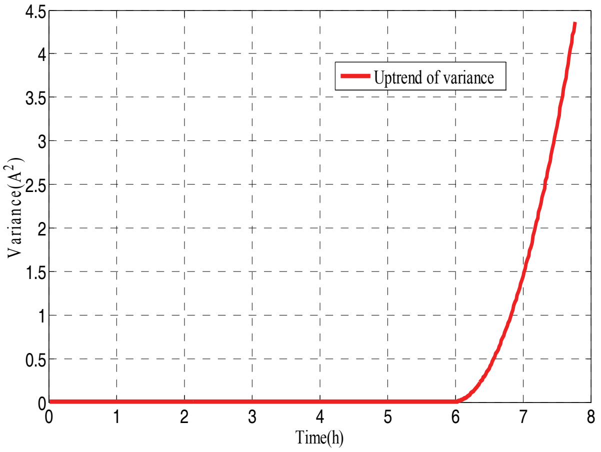

Figure 5: Variance Change Trend of Current Card of Casing Gas Cause Underload Shutdown

Similarly, Figure 6 depicts the variance change trends of different current cards. It can be seen that different current cards have different change trend of variance, such as uptrend or downtrend of variance and mutation of falling. According to the mapping relation in Table 1, we can also know the different working conditions of ESP. Thus, the algorithms proposed above are accurate.

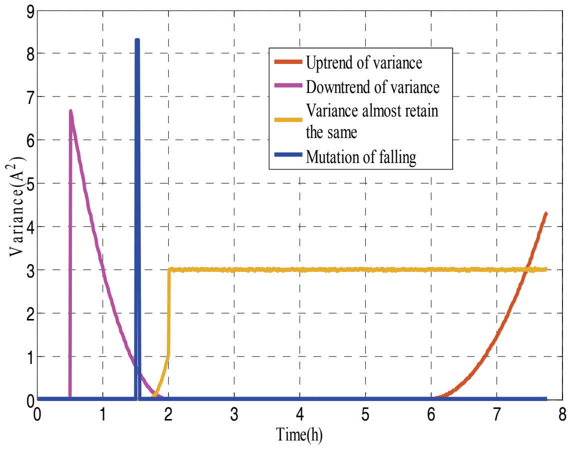

Figure 6: Variance Change Trends of Different current Cards

Case 2: The current is normal fluctuation but with obvious change. Figure 7 shows the current card of motor wear and Figure 8 presents the expectation change trend of current card of motor wear, which shows the current is increasing gradually along with the time change.

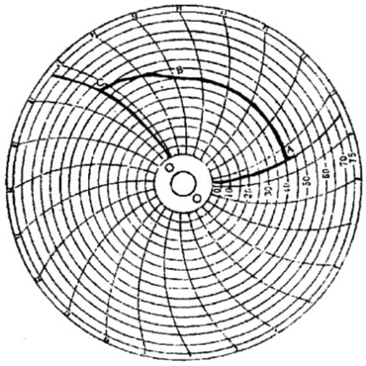

Figure 7: Current Card of Motor Wear

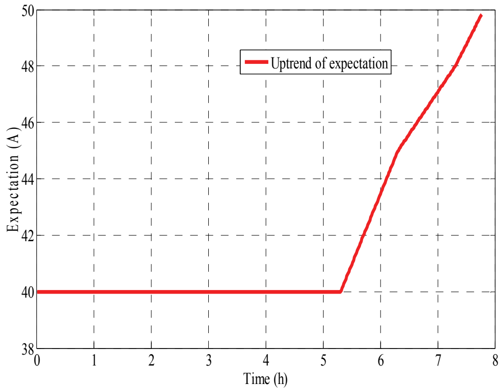

Figure 8: Expectation Change Trend of Current Card of Motor Wear

As shown in Figure 9, expectation has two types of change, uptrend and downtrend respectively. Besides, two or more current cards have the same change tendency of expectation, and other features, such as periodicity in Table 1, need to be taken into consideration now, so the different faults can also be judged correctly.

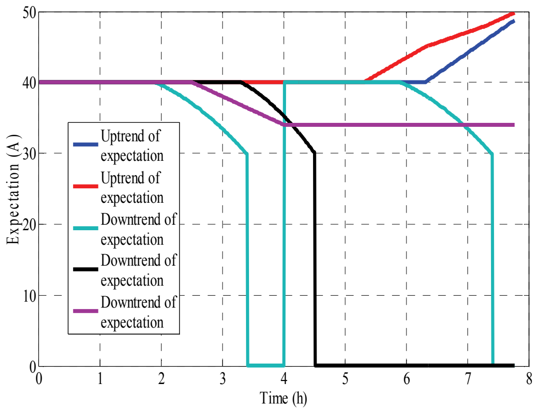

Figure 9: Expectation Change Trends of Different Current Cards

The algorithms designed based on the features extraction can recognize the different working conditions of ESP quite well. In addition, to better diagnose the fault of ESP, the mapping relations between current cards and features in **Table 1** need to be gradually perfected.

5. Conclusions

The algorithms based on the features extraction designed to address the human errors and the ESP timely fault diagnosis problems in this paper, so that some measures can be taken to avoid the unnecessary economic losses. Besides, there are two cases that whether the current is normal or not fluctuations are simulated by using MATLAB to validate the feasibility of the algorithms and simulation results can meet the goals better. In order to reduce the ocean economy losses, we will further research and perfect the algorithms.

In order to develop the ocean economy and to better protect the marine environment, in the future research, we will consider how to employ other fault diagnostic methods, such as if combine the methods of Tao et al. (2012) with Durham et al. (1990), we can get the noise and vibration signals by sensors, then analyze the large database and use the neural network method to diagnose the fault of ESP. Meanwhile, we will research the ESP system mentioned by Li et al. (2003) and improve the simulation model performance of ESP as worked on by Thorsen et al. (1999). Besides, more experiments about ESP faults diagnosis system and advanced fault diagnostics methods (Karimi, 2011; Yin et al., 2014; Zhang et al., 2010; Chadli et al., 2013) will be carried out gradually.

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