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Review on electrical submersible pump failures detection and monitoring system

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ABSTRACT

An artificial lift is a technique for pumping fluids in the petroleum industry today. Most artificial lift that is used nowadays is an electrical submersible pump (ESP). ESP is very convenient and reliable for lifting production. It applies under offshore and onshore industries, where it has high displacement capacity and flexibility to handle various sizes and flow rates under different well conditions. Due to severe operating conditions, ESP may experience fatigue failure, an undesirable malfunction resulting in a shortened service life. Early failure detection on ESP is imperative to prevent a major failure in the pump and reduce the cost of the damage. This study provides an in-depth examination of condition monitoring and early failure detection, with a focus on mechanical and electrical failures. This paper begins with a description of the ESP working principle followed by an analysis of ESP fault and numerous ESP performance monitoring techniques, including the application of early detection. Finally, the authors summarize ESP's failures, including detection methods for each failure. Besides, recommendations for future research to increase ESP's lifetime are also discussed. This review revealed that the lifetime of existing ESP can be extended if extensive monitoring of ESP conditions and advanced fault detection methods are applied.

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1. INTRODUCTION

More than 90% of oil production needs an artificial lift nowadays [1], [2]. Electrical submersible pump (ESP) systems are the most adaptable and multi-skilled among artificial lift techniques of pumping production to the surface in the industry [1]–[9]. The ESP can survive for a long period, making it an extremely durable and robust machine. However, the lifespan of an ESP is only up to 10 years, as it is likely to be damaged due to many factors such as electrical and mechanical and also the corrosive environment around the ESP, thus, making ESP one of the complex machines. The sudden failure of ESP can lead to product disruption, especially in the oil and gas industry where ESP is commonly used to lift the fluid to the surface resulting in significant economic losses [3]. Therefore, this challenge can be overcome by proper condition monitoring for early detection of failures to maintain the efficiency of ESP [7], [10]–[13]. There are methods to detect failures earlier to avoid ESP downtime, which can be costly. By comprehensively improving ESP fault detection and monitoring, the authors positively agree that an ESP can survive for the longest time. There are many research studies on monitoring and failure detection of ESP.

Numerous papers have been written about ESP failures [2], [4], [14], [15], however, to the author's best knowledge, a systematic review of failure focusing on electrical and mechanical parts in ESPs has not been documented in the previous literature. The previous research on ESP failures did not explicitly address specific electrical and mechanical failure detection and monitoring methods. ESP can be categorized into three types of failure such as electrical, mechanical, and operational system failure. This paper only focuses on the details of the failure in ESP, with emphasis on two types of failure: mechanical and electrical. Furthermore, this paper is to determine the optimum condition to operate the ESP to help minimize and avoid failures at early stages. Therefore, the review of failures and detection methods in ESP can improve its efficiency.

Hence, the article briefly introduces the ESP in the introduction part including the components and working mechanism in section 2. Section 3 discusses the various types of ESP faults. Then, ESP performance monitoring is discussed in section 4, followed by the failure detection methods in section 5. The summary of the failure detection method for 2 major failures in an ESP is discussed in section 6. The major challenges and future research related to the practical design and development of machines are discussed in section 7. Finally, section 8 presents the conclusion about ESP failures, condition monitoring, and early failure detection.

2. ESP OPERATING MECHANISM

The majority of the ESP assembly is located downhole [16]. An ESP is a downhole artificial lift technology type. Severe downhole component conditions will lead ESP to electrical and mechanical failures. It is important to highlight that recent research has discovered fault detection and condition monitoring of the ESP to prevent failures [1], [3], [15], [17], [18]. ESP consists of a few components that work together to extend the life of the ESP including protecting downhole components from various conditions that can cause failure [19]. At the surface, the ESP contains the power source and controller, while the downhole contains the power cables, gas intake, protector, and motor, as shown in Figure 1. It also has multistage revolving impeller blades powered by an alternating current (AC) medium voltage submersible motor. A standard ESP is powered by a three-phase asynchronous induction motor. The motor receives electrical power from the surface controls via the electrical cable, converts it to mechanical energy, and sends it to the pump impellers via a coupled shaft [20]. The motor is one of the main components of a submersible pump, so the condition of the motor can significantly affect the operation and efficiency of the submersible pump [21]. The rotation of the blades in the impeller is made possible by converting electrical energy into mechanical energy [16]. The blades are permanent and act as guide channels for the impeller of the next step [22]. The spinning of the impeller blades allows the kinetic energy to transfer to the fluids and then convert to pressure potential at the exit of the impellers by the blades.

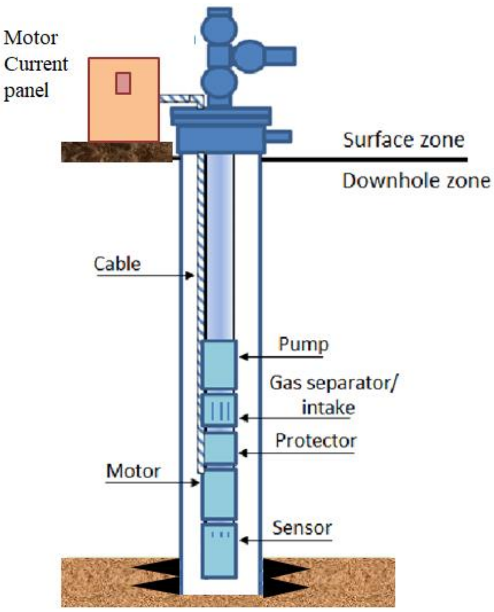

Figure 1. Component of the ESP

An ESP life cycle in a well includes design, installation, operation, troubleshooting, and failure analysis. Design and specification are the first phases at the beginning of the ESP life cycle. During this phase, the manufacturer will release a series of enhancements to the current ESP design to ensure compatibility with current oil production and system operation requirements. The second phase ESP handling and installation is one of the critical periods in which ESP failures can originate from the installation phase if this process is not done properly according to the installation instructions. Scheduled maintenance for operation and troubleshooting is part of the ESP life cycle and must be performed after commissioning [23].

3. ESP FAILURES

Although ESP is a robust machine, it is a very demanding operating environment that results in downtime due to many types of ESP failures. ESP failures in the oil field are frequently sudden and unexpected, making the industry incur large losses. The most common failures of an ESP can be categorized into mechanical failure, electrical failure, and operation failure [16], [24]. Mechanical failures are typically associated with moving components in the ESP assembly. However, they can also involve stationary components in some circumstances. Based on previous studies, mechanical failure that includes shaft breakage [16], [23], [25]–[28], impeller [14], [17], [24], [29], [30] and pump leaking [16], [18] are the common types of faults in the ESP. Electrical failure is common among the three types of failure based on the induction motor in the pump such as bearing [13], [31]–[37], broken rotor bar [38]–[46], and stator winding [47]–[51], that will influence the operation of ESP. Moreover, operational failure can occur due to high temperature [16], [24], [50], high pressure [16], [17], [24], [32], and multiphase flow [16], [24], [51] in the fluid. However, this failure can affect electrical and mechanical components in the ESP.

By understanding and addressing the distinct characteristics of these failures, predictive maintenance strategies can be enhanced to improve the overall reliability and efficiency of ESP systems. This can help reduce unplanned downtime, extend the lifespan of critical components, and optimize maintenance schedules to minimize costs and maximize productivity. Hence, this paper will discuss two categories of ESP failures which are electrical and mechanical faults, and their monitoring and detection methods for specific faults.

3.1. Electrical failure (induction motor-based fault)

The induction motor can be recognized as a pump monitoring sensor since it is used to power the ESP [13]. The motor, the most important component of a submersible pump, is also prone to failure. Continuous use of the motors will affect undesired operating characteristics such as abrupt load changes, additional supply outages, and unbalanced current [48]. Based on Figure 2 the induction motor consists of the main components such as stator winding, rotor bar, and bearing.

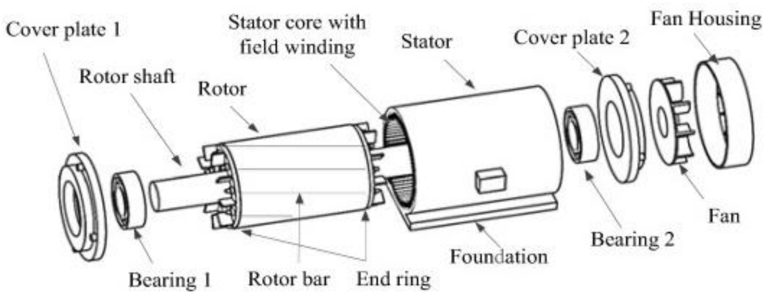

Figure 2. Components in induction motor

The motor itself has two categories of failure in induction motors: electrical and mechanical. Rotor problems range between 5 and 10%, whereas stator electrical faults range between 30-40% [36]. Eccentricity and bearing issues contribute to about 40-50% of all failures [36]. The condition of the motor must be monitored regularly to prevent failures that lead to ESP shutdown.

3.1.1. Broken rotor bar

Broken rotor bars (BRB) are among the failures that are not easy to identify because they usually do not bring any sign of a sudden motor failure. Due to this, the motor will be fully damaged and the production will be stopped [52]. Proper detection is therefore essential to protect the rotor and stop further motor failures [36]. BRB happens because of a combination of stresses acting on the rotor bar due to electromagnetic, environmental, and mechanical factors [36].

3.1.2. Bearing

Bearing faults are common failures in induction motors, with a 40% contribution in the motor failures [12]. This happens because vibration at half the synchronous frequency is linked to bearing rotational [3]. When bearings fail, shaft friction will increase, leading to increases in the temperature of the bearings [10]. Bearing failure also increases the rotational friction of the rotor [53] and is usually damaged by the interaction of their rolling elements, resulting in vibration signals at specific frequencies [32]. Premature failure in the bearing can also occur in other components because of the effect of bearing replacement [35]. Therefore, for an induction motor to operate reliably, mechanical failures in the rolling element bearings must be identified and diagnosed earlier. Since ESP operates in a challenging environment that is exposed to extreme vibration, bearing faults could happen frequently if no advanced monitoring methods are applied.

3.1.3. Stator winding

One of the most common causes of induction motor (IM) failure is an insulation failure in the stator windings, which accounts for 38% of induction motor failure [54]. Stator defects happen because of the insulation. It can lead to crucial failures in motors that can tend to worsen and propagate more quickly. In severe cases, fragments of the rotor bar also can damage the stator winding during operation. Detecting a defect in the stator winding early in the development phase saves additional failures and allows for reliable operation [48]. It is well known that bearing, stator winding, and broken rotor bars are major faults contributing to the induction motor. The detection of motor issues is based on a constant observation of motor performance during operation. If there are any anomalies in the motor, this could be a signal that it is going to malfunction. This also shows that the ESP may be prone to failure if no proper maintenance and early failure detection methods are applied for the induction motor.

3.2. Mechanical failure (ESP components fault)

The mechanical fault is usually related to the components of the ESP. Because of the severe working environment and constant operation, the components of the pump tend to break down. These failures are challenging to mend and usually require the replacement of components. It also can interrupt the operations for the longest time and higher operational costs are needed [8]. Common mechanical failures in ESP include component breakages such as impeller, shaft breakage, pump leakage, corrosion, and dislocation are discussed in this section.

3.2.1. Leakage

Leakage is a common failure in oilfields and occurs in components such as tubing strings, pumps, and oil lines because of the inflow of fluid from the string. This happens when an ESP component assembly fails. The liquid that leaks outside the string will occur regularly as the fluid from the ESP string leaks into the borehole to compensate for the pressure drop, thus reducing oil output. It is consequently critical to discover leaks as soon as possible [18], [19].

3.2.2. Breakage

Operating companies suffer greatly from pump shaft breakage, as it leads to economic loss because production stops [55]. When powered by low-voltage soft-starters, ESP shafts are significantly more prone to dynamic torsion due to their greater axial length. With the soft-starters experienced, shaft failure can be detected earlier during motor startup. When the ESP motor is started directly from a power supply, it produces a high initial current that may be up to nine times the rated current from the motor, resulting in significant mechanical strain on the system. This can put too much strain on the ESP shafts and connections, leading to ESP breakdowns [4].

Furthermore, misalignment can occur due to the center lines of two connected shafts not lining up when in use. This happens because of shaft shifted from its initial place [27] as shown in Figure 3. Fractures of components can cause malfunction and failure of downhole components. To avoid this, the ESP must be monitored regularly to prevent failures that affect the motor.

3.2.3. Impeller

An impeller is a rotating component of an ESP that is usually constructed of iron, steel, or bronze and is used for increasing fluid flow and pressure [28]. When a significant ESP is employed, more stress is put on the impeller because the material reliability of the impeller is insufficient. These characteristics, together with the tension caused by friction between the impeller and the pump, indirectly increase the probability of fracture [56]. Additionally, the number of vanes in the impeller is finite. Each vane modifies the flow and produces an impulsive effect that influences the current through the dynamic torque [13]. Due to impeller flaws, the rotating components of the ESP have eccentric or unbalanced masses, which produce unbalanced forces. When an imbalanced force is excited, the system's vibration response alters [10]. Therefore, it is necessary to promptly identify faults in the impeller to guarantee the secure and dependable operation of rotating machinery. Consequently, an appropriate signal-processing technique must be employed to identify failures.

The defection of these changes in the motor current signals also allows monitoring of the health of the impeller [13]. Figure 4 shows the downhole submersible parts, Figure 4(a) shows the impeller without any fault. Meanwhile, Figure 4(b) shows an example of how the impeller failure can influence the ESP in which the vanes are missing.

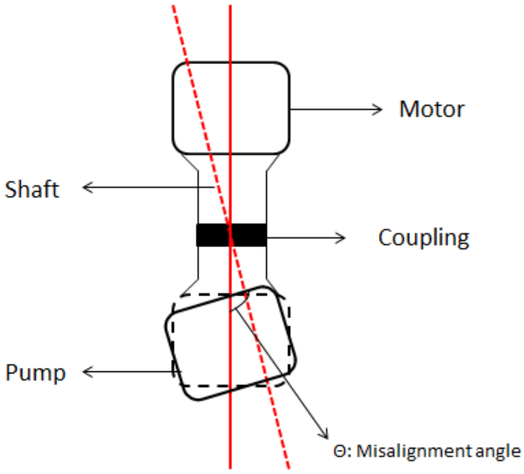

Figure 3. Misalignment between the motor load and shaft [15]

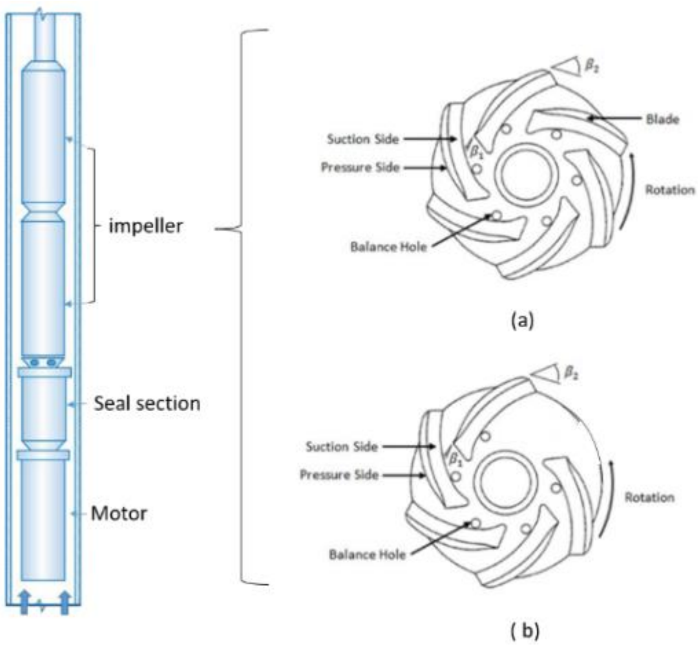

Figure 4. Downhole submersible parts of (a) healthy impeller and (b) broken impeller [15]

3.2.4. Other common failures

Corrosion and discoloration are two additional typical mechanical issues in submersible pumps. The presence of corrosive components such as hydrogen sulfide, chlorine, and total dissolved solids in well fluid enhances electron migration. Such migration leads to severe corrosion, especially when different metals are utilized in artificial lift well completions. Carbon steel tubular and casing are easily damaged by such corrosive compositions, resulting in premature failure of artificial lift completions, and causing safety and operational concerns [57]. Dislocation can happen for various causes, including downhole component fracture, bolts, bearings, and shafts. Dislocation first affects the components. Multiple component failures may occur if the impacted component is part of a string [16]. The specific failure due to under voltage is caused by an insufficiently controlled main power supply or a wiring problem and a power failure is caused by unbalanced phases, voltage spikes, the presence of harmonics (distorted current and voltage), or lightning strikes. This specific failure can cause the pump motor to overheat, resulting in a motor failure [20]. Table 1 summarises the most common failures in the ESP and their respective impact. Based on the table, mechanical failures have been more found than electrical failures in the application of ESP. This is due to the components of ESP that are more exposed to failures making it complex.

Table 1. Extensive list of failures and impact

Fault	Type	Cause	Impact	Sources
Broken Rotor Bar	Electrical	Combination of stresses acting on the rotor, electromagnetic, thermal dynamic, environmental, and Mechanical Factors	The amplitude of the torque decreases, and more fluctuation and mechanical vibration occurs	[36], [37]
Bearing	Electrical	Lack of lubrication, mechanical stress, misalignment corrosion, damage to the inner and outer race	Increase in the shaft friction, temperature increase, and rotation friction of the rotor increase	[22], [23]
Stator Winding	Electrical	Insulation failures, fragments of the rotor bar during operation	Phase to phase or phase to ground short circuit	[18], [32]
Breakage	Mechanical	Mechanical stress, two coupled shafts do not align, strong vibrations	Shaft misalignment, malfunction, and failure of downhole components	[9], [27]
Impeller	Mechanical	Scale buildup in the pump stages, inevitable cavitation, erosion	The rotating part of ESP unbalanced masses blocks the flow of the fluid in the pump	[29], [33], [58]
Leakage	Mechanical	Broken components especially protector	Can reduce oil production	[3]
Corrosion and Dislocation	Mechanical	Stress corrosion cracking, highly corrosive condition	Pump Motor Overheat	[3], [34]

4. ESP PERFORMANCE MONITORING

In recent years, industries that use rotating machinery have become increasingly concerned with monitoring diagnosis, and prediction of the machine. With advancements in sensor technology and the internet of things (IoT) today, real-time data analysis may be used to evaluate the state of machines in the field for purposes of maintenance and repair, improving machine productivity, reducing breakdowns, and minimizing maintenance and downtime cost expenses [30]. ESP is frequently constantly controlled because of the comparatively higher maintenance cost due to unexpected shutdowns and breakdowns [59]. To monitor the ESP, various parameters of a pump during operation will be measured to observe the mechanical conditions. Hence, it is important to prevent the failure from happening or at least monitoring the ESP will reduce the rate of failure to ensure that the ESP can operate at its best performance.

4.1. Vibration analysis

Vibration-based approaches are the most common monitoring techniques because it’s dependable, non-intrusive, and simple to measure [60]. It is employed in various sectors, including material handling, aircraft, and power generating to monitor and maintain the health of the machine, prevent failures, and minimize downtime of the machine [35]. It can help identify various faults and abnormalities in a system such as unbalance, shaft misalignment, and bearing faults. Processing the vibration signals is required to identify the important components, remove nonlinear effects caused by the cover frame, and filter out background noise [61]. Most vibration measurements employ vibration-acceleration sensors, which operate based on the piezo-electric effect and produce an output voltage proportional to the force applied to the sensor [60]. Additionally, the vibration analysis method has benefits such as low instrument costs, simplicity of installation, and the capacity to get precise results of the damaged area, which leads to more reliable results [28].

4.2. Intake temperature and intake pressure

Downhole pressure data can be used to optimize output and identify issues that could lead to an oil well shutdown. Several sensors near the downhole can monitor the operational conditions of downhole equipment [17]. The temperature of the fluid can affect the ESP system's performance and efficiency. At different temperatures, oil and water have different viscosity and densities. These features influence the pump's ability to handle fluid and whole performance. Thermocouples have been installed closest to the pump intake as downhole sensors to measure the temperatures [50]. Thus, production pressure and temperature are measured at the bottom hole by a series of sensors and transferred to the surface for processing via a communication system. The data from the downhole sensors will enable both a direct measurement of ESP and an analysis of the performance trends of the ESP system, including the field of production. These patterns notify professionals in advance of the appearance of potential issues with surface and subsurface equipment, enabling them to take action to solve them and avoid system failure.

5. FAULT DETECTION METHOD

Installation, manufacture faults, tolerance, working environment, and maintenance schedule mostly cause failures in ESP [10]. Engineers and technicians face a difficult task in maintaining the ESP because of unexpected electrical or mechanical failures. Submersible motor fault detection has become vital in ESP to prevent unexpected breakdowns and minimize unscheduled downtime [10]. Therefore, according to Sabir *et al.* [39] currents and vibration signals can used as parameters to identify both types of failures in ESP. This segment provides a review of various techniques and advances in the detection and diagnosis of ESP failure namely the support vector machine (SVM) and motor current signature analysis (MCSA).

5.1. The support vector main approach

In the ESP, the widely utilized and adaptable SVM is used to solve classification issues [62]. Furthermore, before extracting the characteristic values linked to the failures, the data gathered by the ESP production system is first filtered and eliminated. To detect a data anomaly, the calculation of denoising autoencoder's (DAE) threshold value for normal data and comparing it to the estimated amount of the input data's reconstruction error. The unusual problems were expected. Using the genetic algorithm (GA) optimization technique, the SVM model's performance is enhanced when fault diagnosis is performed on data that exhibit abnormal patterns. The input is made up of data with odd patterns [18]. Patel and Bhalja [63] applied SVM to detect the failure in healthy and faulty induction motors as it has 98% accuracy in separating the healthy and faulty condition of the motor [63]. Gangsar and Tiwari [61] used SVM to detect the mechanical and electrical faults in induction motors. To get the best performances of SVM, the experiment was done using three different signals which are vibration, current, and vibration-current signal [64]. The method of SVM has been used widely in the industry to detect failure, however, for large parameters of the induction motor, the method must be retrained as SVM cannot be applied to large data variations.

This method can also identify an uncommon situation and clarify an imminent defect, allowing the formulation of an appropriate advanced solution [18]. The application of SVM for fault diagnostics in ESP systems has shown promising results, with the ability to effectively classify different types of failure. However, as the complexity of ESP systems increases, the limitations of SVM in handling large data variations and high dimensionality become more apparent [65], [66].

5.2. Motor current signal analysis

MCSA has been widely used to detect failures in ESP and other pumps [13]. MCSA is a current analysis of the induction motor that powers the submersible pump. This method is part of electrical analysis, which has become an independent and effective method due to the simplicity with which current and voltage signals can be detected [13], [67]. Electrical signals that have been properly analyzed are significant because they can discriminate between healthy and inadequate ESP operation, efficiently extracting important information from the signal [13].

In addition, mechanical signals can also be detected using these electrical signals because of knowing that failures in the components might induce torque and eccentricity fluctuations in variation currents and voltages. MCSA is the method for identifying the failure during the motor is operated normally which frequency can be identified as related to frequency domain faults of the current [40], [68].

MCSA is a common technique for fault detection in ESP. It can provide early warnings of ESP failures, assisting in preventive maintenance and minimizing downtime. In the previous study, Afrizal and Ferrero [15] proposed MCSA to detect shaft misalignment failure in ESP and gave accurate measurements as the method was successfully applied [15]. Pradhan *et al.* [13] applied MCSA to detect the broken impeller in the ESP by comparing the signal processing technique. Motor current measurements are a non-invasive method that does not need sensors to be installed making it easy to implement without interrupting the operation making it one of the convenient tools to monitor the ESP operation.

Raw motor current signals may exhibit subtle variations that can indicate an emerging fault. Signal processing methods are capable of isolating these variations, amplifying them, and converting them into a distinct pattern that corresponds to a specific type of fault. Therefore, proper signal processing techniques are crucial for effective fault detection since they track important signal data. For the fault diagnosis, Hilbert-Huang transform (HHT), fast Fourier transform (FFT), short-time Fourier transform (SFT), continuous wavelet transforms (CWT), discrete wavelet transform (DWT), and Wigner-Ville transform recently utilized by researchers to improve the diagnosis as a signal processing technique to detect the fault. In conclusion, the continuous advancements in signal processing methods have significantly enhanced the effectiveness of motor current signature analysis for fault detection and diagnosis in electric motors and pump systems.

6. SUMMARY OF THE ELECTRICAL AND MECHANICAL FAULT DETECTION METHOD

Based on the discussion, as mentioned earlier, ESP has 3 types of failures: electrical, mechanical, and operation fault. However, this paper only focuses on 2 types of failures: electrical-based failure on induction motor and mechanical-based failure on ESP. In some mechanical failures, motor current as an electrical signal is used as a detection parameter. Certain faults have certain methods but have different accuracies depending on the failure. Based on Table 2, ESP has several common failures in induction motors and the components of ESP. Table 2 outlines the failure detection methods for each fault, which vary depending on the suitability of the method for ESP operation. Based on this, mechanical fault and electrical fault have an accuracy level of detection that may vary due to the many factors including the signal processing technique applied. Some of the machine learning methods do not require signal processing techniques as they use direct data or signals from the components. From this table, it shows that MCSA and machine learning are the common methods due to their effectiveness and better detection accuracy. However, interpreting the diagnosis of the failure by using the machine learning method is not easy to use in complex situations as it takes considerably more time even though this method has better accuracy. Furthermore, certain faults such as broken shafts, rotor bars, and bearings can be detected by monitoring the vibration. Hence, MCSA is a non-invasive method suitable for both electrical and mechanical failure detection on ESP.

Table 2. Summary of failure detection of ESP

Types of Faults	Monitoring Method			Signal Processing Technique	Sources
	MCSA	Vibration/Pressure	Machine Learning Diagnosis		
Broken Shaft	/			FFT, Frequency analysis	[15], [25]
		/		FFT	[15], [26]
			/	-	[2]
Impeller			/	-	[28]
	/			FFT, STFT, CWT	[13]
Leakage			/	-	[18]
Broken Rotor Bar		/		Wigner-ville, CWT, DWT, HHT	[36]
	/			FFT, STFT, Wigner-ville, CWT, DWT, HHT	[36], [40], [44]
			/	-	[38], [43]
Bearing	/			Wavelet Transform	[29], [35]
			/	Hilbert Transform	[12], [24]
		/		FFT, Wavelet Packet Energy	[30], [31], [34], [35]
Stator Winding	/			FFT, STFT, CWT	[47], [49]
			/	Wavelet Transform, STFT	[46], [48]

7. PRACTICAL CHALLENGES

Abundant research on ESP failures and their operational improvements has been ongoing for several decades. However, several study ideas may be considered in the future. Based on the extensive literature review, the authors found that more research focuses on mechanical failures for ESP applications than electrical failures even though there is a correlation between electrical and mechanical failures. In addition, the lack of recent journal publications from 2017-2024 has made it difficult to find papers that focus on the electrical failures of ESP. Most ESP fault detection methods have different accuracy levels. The researcher can extensively identify the ESP failures related to the induction motor. In the future, the research can focus on developing a specific prediction model for specific fault detection since each component has different parameters. For example, by introducing a specific method to detect the failure in shaft misalignment faults that consider different sizes of ESP. The IoT is becoming more applicable in numerous engineering areas.

However, this method is still less explored. Therefore, it would be beneficial if an IoT system could be designed and used effectively to monitor the whole ESP system. Condition monitoring will be possible even without visiting the actual site, and data collecting will be possible from remote locations. Finally, since the induction motor is a main part of the submersible pump, it can have different defects that will affect the whole operation. Therefore, any solutions aimed at predictive maintenance should consider both sides of electrical and mechanical component failure. Since there are multiple faults, they will be difficult to detect because of interconnections, which leads to them not being detected clearly and inaccurately.

8. CONCLUSION

ESP is a common artificial lift method that is used widely to lift abundant oil from the bottom of the sea which makes it a complex machine. Components of ESP including mechanical and electrical are at high risk of failure because of the harsh conditions such as high temperature, high pressure, and free gasses. To avoid being time-consuming and costlier to maintain the performance of ESP, three different methods have been approached to monitor the condition of the ESP, namely, vibration analysis followed by pressure and temperature measurements. Most of the faults with ESP assembly are interconnected and may exacerbate or contribute to other problems. This means that preventing some faults can help you prevent a lot of other problems. To increase the lifespan of the ESP downhole, this in-depth research investigates the most frequent ESP failures and makes an effort to determine the optimal technique for condition monitoring and early fault detection for these failures. Great attention must be paid to improving the signal transformation errors to ensure an appropriate output signal. The research of the paper suggests a specific prediction model for specific faults, an IoT system to monitor the condition of ESP and a system that can diagnose the fault and their severity in real-time. The improvements applied in ESP laboratory tests and field trials will be discussed in future work. The authors anticipate that this approach will assist others, particularly researchers, engineers, and manufacturers, in improving ESP design, operation, and life cycle.

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