Real-time Insulation Monitoring System for Electric Submersible Pump

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Abstract. As one of the most important mechanical oil production equipment in the process of oil and gas production, electric submersible pump has a cycle of up to half a year for working. During the operation of the electric submersible pump, the insulation condition of the system will gradually aging, resulting in defects in the system and causing destructive failure. In order to solve this problem, this paper designs a real-time monitoring system for the insulation condition of electric submersible pump, and constructs the indoor well condition simulation experiment. Compared with the existing insulation detection technology, the monitoring technology is simple and does not need professional technical support from inspectors.

1. Introduction

For electrical products and large industrial devices, there are strict and clear regulations on insulation. If the insulation test fails, it will be regarded as a fatal defect and retest is not allowed. The real-time monitoring of the insulation condition of the system to ensure the good insulation performance of the system plays an important role in the safe operation of electrical products and industrial devices.

In order to ensure the safe use of electric submersible pump, insulation test should be carried out before it goes into the well. According to different requirements, 2.5kv-10kv megger is generally used for insulation test.[¹] However, this method can only ensure the reliability of the electrical submersible pump well insulation before the well, and can not measure the insulation performance of the system in real time when the electric submersible pump well is working. Once the insulation of the electric submersible pump well is aging and there is no corresponding data support, the staff can not predict the working condition of the electric submersible pump well, and there is no way to take corresponding solutions. In order to know the insulation performance of electric submersible pump well under long-term operation, the electric submersible pump must stop working and pull out all the tubing, which is a waste of time and money.

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The other is to detect the leakage current of the unit. When the downhole secondary instrument provides back pressure downward, the reverse parallel secondary pipe is connected, and the underground circuit part is bypassed, and other parts cannot work. At this time, the current in the system circuit is the unit leakage current. The disadvantage of this method is that it needs to start and stop the ESP monitoring system frequently, and can not monitor the insulation condition of the system in real time. At present, there is a very mature measurement standard for leakage current measurement of household appliances in China, but this measurement method can only be measured by qualified testing institutions. Users can not measure the leakage current of household appliances in real time. This paper studies and designs a real-time monitoring system for the insulation condition of electric submersible pump. It is different from the general insulation detection system and has the limitation of insulation condition. Compared with the existing insulation detection technology, the monitoring technology is simple and has a good application prospect.

2. Monitoring system of electric submersible pump and downhole condition

Figure 1 shows the model of electric submersible pump and downhole monitoring system.
The system is divided into surface system and underground system. The ground system mainly consists of artificial star point, main control unit and filter. The underground part is mainly composed of underground monitoring circuit, armored cable, three-phase winding motor and filter circuit. The downhole monitoring circuit converts the monitored downhole sensing signal into 4 ~ 20mA standard signal current, and then transmits it to the downhole system through the cable armor. The downhole system receives the downhole signal current transmitted from the underground, and through AD acquisition, processing, display, real-time monitoring of underground working conditions. The armored cable is a three-phase power supply line of high-voltage power grid. An insulating layer is wrapped on its outer side to isolate ionization and protect the cable. A layer of armor is coated on the outside of the insulation layer, which is used as the transmission line of the underground monitoring circuit to transmit the underground DC signal current.

In the long-term operation of submersible pump, its insulation condition will gradually aging, and insulation aging point will appear. The three-phase power supply line will form a loop with the cable armor through the insulation aging point, resulting in insulation leakage.

From this, we can get that there are both DC signal current and AC leakage current representing the working condition of submersible pump system on the sheath of submersible cable.

3. The Principle of real time monitoring leakage current of electric submersible pump

![Figure 2. Schematic diagram of current transformer](image)

Current transformer (CT) is an instrument to measure the current by converting the high current at the primary side to the small current at the secondary side according to the principle of electromagnetic induction. The current transformer is a dual power supply device because it measures alternating current. When the AC current is amplified, the negative half axis of the signal cannot be amplified if it is supplied by a single power supply. Based on the principle of electromagnetic induction, current transformer can only measure alternating current, but not DC signal current which represents underground working condition.

The cable sheath transmits 4 ~ 20mA DC current signal to the ground system. At the same time, if the system insulation fault occurs, the three-phase power supply line will form a loop with the cable sheath through the insulation aging point, resulting in AC leakage current. The insulation condition of electric submersible pump well can be monitored in real time when the current transformer is sheathed on the cable sheath led up by the downhole monitoring system.
4. Real time monitoring system of electric submersible pump leakage current based on current mutual inductance principle

The principle of real-time insulation monitoring of electric submersible pump is shown in Fig. 3.

When the multi parameter monitoring system of ESP and ESP well works normally, the DC signal current monitored by downhole monitoring circuit is transmitted to the multi-channel AD acquisition module through the cable sheath, and the channel 1 is transmitted to MCU. If the insulation is aged, a circuit is formed between the three-phase power line and the cable sheath, resulting in leakage current I. The current transformer is sheathed on the cable sheath led up by the underground monitoring system, and the leakage current value I is measured.

For the sake of system consistency, the measured leakage current is transformed into 4 ~ 20mA standard DC current signal I_f. I_f is transmitted to MCU through channel 2 of multi-channel AD acquisition module. MCU transmits the simulated value of leakage current collected to the upper computer, and the upper computer draws the insulation curve in real time according to the transmitted leakage current value. The staff can observe the aging of the insulation of the electric submersible pump well system with time, and predict the insulation condition of the electric submersible pump well system and make corresponding measures in time.

At the same time, MCU will receive the analog value of leakage current through LCD display screen real-time display. The staff can monitor the insulation of electric submersible pump well system at any time. And MCU will measure the leakage current value I and the long-term working experience of the electric submersible pump well leakage current value to infer whether the insulation performance of the electric submersible pump well system has aged. If the I value is abnormal, the electric submersible pump well has insulation fault, the MCU control alarm module will alarm, at the same time, the submersible pump well will stop working, and the staff will carry out maintenance on the electric submersible pump well system.
5. Well condition simulation experiment and test results

Figure 4 shows the experimental platform. The AC circuit composed of AC power supply and variable load represents the insulation leakage circuit of the submersible pump, which is transmitted to MCU through channel 1 of multi-channel AD acquisition module. The underground monitoring circuit transmits the DC signal current detected by the sensor to channel two of multi-channel AD acquisition module. As shown in the figure, connect the relevant hardware circuit, adjust the adjustable load of the insulation leakage circuit of the electric submersible pump to obtain multiple groups of measured values.

Table 1. Monitoring data of electric submersible pump leakage current real time monitoring system

| Ammeter reading/mA | Module acquisition current/mA | relative error/% | LCD display/mA | relative error/% | Upper computer interface/mA | relative error/% |
|--------------------|-------------------------------|------------------|----------------|------------------|----------------------------|------------------|
| 4.000              | 4.000                         | 0.000            | 4.000          | 0.000            | 4.000                      | 0.000            |
| 6.758              | 6.756                         | -0.020           | 6.755          | -0.044           | 6.755                      | -0.044           |
| 7.283              | 7.283                         | 0.000            | 7.284          | 0.013            | 7.282                      | -0.013           |
| 8.159              | 8.158                         | -0.012           | 8.158          | -0.012           | 8.158                      | -0.012           |
| 10.167             | 10.165                        | -0.019           | 10.170         | 0.029            | 10.170                     | 0.029            |
| 13.672             | 13.670                        | -0.014           | 13.671         | -0.007           | 13.672                     | 0.000            |
| 15.718             | 15.725                        | 0.040            | 15.725         | 0.040            | 15.724                     | 0.038            |
| 17.669             | 17.672                        | 0.016            | 17.671         | 0.011            | 17.671                     | 0.011            |
| 18.772             | 18.772                        | 0.000            | 18.775         | 0.015            | 18.772                     | 0.000            |
| 19.724             | 19.726                        | 0.010            | 19.725         | 0.005            | 19.725                     | 0.005            |
Figure 5. Comparison of real-time monitoring system data between upper computer and display screen

It can be seen from table 1 and figure 5 that the average measurement error of the insulation real-time monitoring system is less than 0.04%, with good real-time performance. It can monitor the insulation condition of the electric submersible pump in real time, and the operation is simple and has a good application prospect.

6. Conclusion
In conclusion, a real-time monitoring system for insulation condition of electric submersible pump is designed in this paper. Based on the model of electric submersible pump (ESP) and real-time monitoring system of downhole state, the signal current and insulation current of ESP are divided into DC current and AC current. Based on the electromagnetic induction principle of transformer, the DC signal current of the downhole monitoring circuit of electric submersible pump is filtered out, and the insulation AC current is extracted. The indoor well condition simulation experiment shows that the system is easy to operate and can monitor the insulation condition in real time, and has a good application prospect.

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