Research and application of intelligent control system for variable speed operation of pumping unit

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Abstract: At present, the pumping machine lifting technology still has problems such as low efficiency, high energy consumption and short pumping cycle. In order to further improve the level of artificial lifting technology of pumping wells, achieve quality and efficiency, save energy and consume reduction, huabei oilfield has developed an intelligent control system for variable speed operation of pumping unit, which takes “closed-loop control technology”, “flexible control technology” and “variable speed operation technology” as a core, and sets digital supporting technology such as “mobile intelligent management and control”, “big data analysis” and “OPRS intelligent expert” as a whole. The system successfully applied more than 600 wells in Huabei Oilfield. Through large-scale on-site application, intelligent control system for variable speed operation of pumping unit realizes the most economical production with minimum energy consumption, achieves the goal of energy saving and consumption reduction, and enhances the intelligent production management level of the oilfield.

1. Introduction
In China's oilfield production, mechanical oil production wells account for 98% of all oil wells, and the beam pumping unit wells account for 96% of all mechanical oil production wells. At the same time, the major oilfields have been in the middle and late stages of development. With the deepening of the inferiority of resources, the working conditions of oil wells have become more and more complex, and the proportion of low-yield, low-efficiency wells and producing fluctuating wells has increased year by year. Crude oil has become more difficult to mine, and the stable production situation is grim.

A new technical means is urgently required to further improve the production management level of pumping wells, to achieve energy conservation, efficiency increasing, production increasing, and consumption reducing. To this end, a new type of intelligent control system for pumping wells was developed to realize the automation of the production process, the visualization of production orders, the scientiaion of analysis and decision-making of the intelligent production of pumping wells, and the oilfield quality improvement and sustainable development was promoted.

2. overall ideas and structure of the system
In the construction of the intelligent control system of the pumping well, the three technical objectives of the system are first established: (1) The pumping well can actively adjust the operating system according to the change of the oil supply in the oil well, and realize the attack-platoon relationship from passive regulation to active coordination, and the control mode from extensive to fine; (2) The driving mode is from rigid to flexible, reducing pole stress and motor energy consumption, improving
system efficiency and prolonging pump inspection cycle; (3) "Internet + Big Data" technology is used to explore a new means of pumping well control to achieve digital production decision-making functions. Based on these three technical ideas, the intelligent control system for variable speed operation of pumping wells was developed.

In the framework of the intelligent control system for variable speed operation of pumping wells, the operating mode of the pumping well includes two types: power frequency operation mode and frequency conversion operation mode. Among them, the frequency conversion operation mode is the core of the intelligent control system, it integrates closed-loop control technology, flexible control technology, variable speed operation control technology and mobile intelligent management and control technology, and completes the three major technical objectives of supply and discharge coordination, energy saving and cost reducing and digital management. As shown in Figure 1.

Figure 1 Frame diagram of intelligent control system for variable speed operation of pumping unit

3. **Key technology of intelligent control system**

3.1. **Closed loop control technology of pumping unit well**

The closed-loop control technology uses the oil production volume or the dynamic liquid surface depth of the pumping well as the control basis for adjusting pumping work system of the pumping well. First, the intelligent terminal equipment (mobile phone, tablet, etc.) sends data reading commands to the closed-loop controller, after receiving the above instruction, the closed loop controller starts to communicate with the well field RTU to obtain the current ground indicator diagram data and the running stroke of the pumping well, the closed loop controller calculates the current pumping efficiency of the pumping well based on the ground indicator diagram data, and the data is sent to the intelligent terminal equipment for display. The on-site technicians set the target pump efficiency on the intelligent terminal equipment according to the current pump efficiency of the pumping well. The intelligent terminal equipment calculates the target rate according to the closed-loop coordination calculation formula, and sends the target rate to the closed-loop controller in the form of an instruction, after receiving the instruction, the closed-loop controller controls the variable frequency controller to adjust the operating frequency of the system to achieve the purpose of changing the rate. If the adjustment does not achieve the desired pumping efficiency, repeat the above operation. As shown in Figure 2.
3.2. Flexible control technology of pumping unit well

The flexible control technology is based on the principle of “current monitoring-frequency control-load verification method”. It consists of four parts: flexible controller, frequency converter, temperature-sensing flow switch and flexible control panel, the flexible controller is the backbone of the whole system, it is responsible for the analysis and processing of the data and the output of the results; the inverter is the direct controller of the motor to achieve variable speed and constant power operation; the temperature-sensitive flow switch utilizes the temperature change of the wellhead over-current pipeline, and it is responsible for measuring the amount of liquid per rate of the pumping well, and mark the rotational position of the pumping unit crank by monitoring the current. The basic principle of realizing the flexible operation of the pumping well is: wired connection flexible controller, frequency converter, temperature-sensing flow switch, the flexible control panel is used to set the basic operating parameters of the pumping well, and the flexible controller monitors the crank position data according to the current, uses the built-in flexible control algorithm performs analysis and calculation, and outputs the analysis and calculation result to the frequency conversion controller. The frequency converter outputs a specific frequency at a specific time according to the received analysis processing result, thereby controlling the motor to output different powers at different stages, and realizing the on-demand output of the oil motor power, the fluctuation of the pumping unit load is reduced, the ground drive and the fatigue of the pole are reduced by adjusting the motor speed and the speed distribution during the plunger pumping process, it achieves the purpose of improving working conditions and extending the pump cycle.

It can be seen from Fig.3, under the normal power frequency operation, the peak power is 87.67 KW, the peak power after the flexible optimization is 49.83 KW, the change trend of the power curve becomes slow, and there is a phenomenon of negative work before the flexible optimization, the impact of negative work on the system is eliminated under the flexible operation, "peak clipping and valley filling" are achieved. As shown in Figure 3.
3.3. **Pumping well shifting operation control technology**
When the motor runs at a constant speed, the operation law of the polished rod of the pumping well is a mandatory quasi-sinusoidal operation law, it does not consider the changing factors of the oil well working condition. But if the motor changes speed, it can adjust the running speed of polished rod by changing the motor speed when there is no optimization space for regulating the pumping time of oil well, and then changes the running ratio of the up-and-down stroke, further optimizes the working condition of the well without changing the operating rate of the well, and achieves the effect of “excellent superiority”. The mathematical model is established to provide the basis for automatic learning, and the value of the frequency of each operating phase and the distribution time of the corresponding frequency are determined. After the frequency variation curve is determined, the motor output frequency is in strict accordance with this curve, and the oil well distributes and runs according to this frequency, the optimal operating condition of the pumping unit is achieved.

3.4. **the mobile intelligent control technology of pumping well**
Using the "Internet + APP Control" technology, the auxiliary decision functions such as production calculation, working condition diagnosis and parameter optimization are transplanted from the background PC end to the front end. Through establishing universal data communication interface among the data acquisition sensor, the industrial control RTU and the intelligent terminal device, and deploying the corresponding APP application on the intelligent terminal equipment (mobile phone, tablet, etc.), the well field autonomous acquisition and analysis processing of pumping unit well electric parameters and load displacement data are realized, and the analysis and processing results are visually displayed on the intelligent terminal equipment. Through the connection of various business models based on big data analysis and application, OPRS expert system, knowledge base and other systems, the on-site staff can fully understand the real-time working conditions of the oil well without being restricted by the geographical space. The production and management efficiency are greatly improved.

4. **Field test and application**
The technology successfully applied more than 600 wells in Huabei Oilfield from 2015 to 2018. As tested by the relevant energy conservation department in Huabei Oilfield, the average energy saving rate of single wells reached 17.14% and the system efficiency increased by 5.38 percentage points.
Taking the XL10-47 well and the Y63-140x well in Huabei Oilfield No. 1 Oil Plant as an example, the application results of the variable speed operation intelligent control system are further evaluated from the detailed parameters of the machine mining system. Before the implementation of the variable speed intelligent control technology, the XL10-47 well and the Y63-140x wells were all operated in the power frequency mode, and then converted to the inverter mode operation. The results of energy saving and production increasing before and after implementation are shown in Table 1 and Table 2.

It can be seen from Table 1 that after applying this technology, the daily output of XL 10-47 well
increased by 0.11t, the pump efficiency increased from 29.35% to 63.11%, the maximum load decreased by 19.1kN, and the daily power consumption decreased 36.43 kW•h, the system efficiency increased by 8.6 percentage points, and the power consumption per ton of liquid per 100m reduced by 0.27 kW•h. It can be seen from Table 2 that after applying this technology, the maximum load of Y63-140x well decreased by 10.62kN, the daily power consumption decreased by 150.5kW•h, the system efficiency increased by 2.94%, and the liquid consumption per ton of liquid per 100m The electricity dropped by 0.12kW•h.

Table 1 running effect comparison table before and after implementing intelligent control technology of variable speed operation of XXX well

| Operation mode | Pump diameter (mm) | Pump deep (m) | Stroke (m) | Speed (Min⁻¹) | Liquid production capacity (l/d) | Pump efficiency (%) | Degree of balance | Maximum load(kN) | Active power (kW) | Day-power consumption (kW•h) | System efficiency (%) | Per ton of liquid per 100m electricity consumption (kW•h) |
|----------------|-------------------|--------------|-----------|--------------|---------------------------------|-------------------|------------------|-----------------|----------------|------------------------|-------------------|-----------------------------|
| Power frequency operation | 38              | 1963        | 4.8       | 3.75         | 8.25                             | 29.35             | 1.12             | 86.9            | 6.29          | 151.03                  | 27.06             | 1.02                        |
| Frequency conversion operation | 38              | 1963        | 4.8       | 1.51         | 8.36                             | 63.11             | 1.21             | 67.8            | 4.78          | 114.6                  | 35.66             | 0.75                        |
| Difference comparison | 0.11            | 33.76       | 0.09      | -19.1        | -1.51                            | -36.43            | 8.6              | -0.27           |                           |                        |                             |

Table 2 running effect comparison table before and after implementing intelligent control technology of variable speed operation of XX well

| Operation mode | Pump diameter (mm) | Pump deep (m) | Stroke (m) | Speed (Min⁻¹) | Maximum load (kN) | Active power (kW) | Day-power consumption (kW•h) | System efficiency (%) | Per ton of liquid per 100m electricity consumption (kW•h) |
|----------------|-------------------|--------------|-----------|--------------|-----------------|-------------------|------------------------|-------------------|-----------------------------|
| Power frequency operation | 38              | 1946        | 4.8       | 4            | 88.34           | 11.75             | 282                    | 20.81             | 1.30                        |
| Flexible operation | 38              | 1946        | 4.8       | 2            | 77.72           | 5.48              | 131.52                 | 23.75             | 1.18                        |
| Difference comparison | -10.62          | -6.27       | -150.5    | 2.94          | -0.12           |                   |                        |                   |                             |

5. Conclusion

(1) Field application shows that the intelligent control system for the variable speed operation of the pumping unit realizes the most economical output with minimum energy consumption, achieving the purpose of improving quality and efficiency, saving energy and reducing consumption.

(2) The on-site application of the intelligent control system for the variable speed operation of the pumping unit greatly reduces the workload of on-site management, improves the work efficiency of the on-site management personnel, and further improves the intelligent control level of production.

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References

[1] Hancheng Liu. Calculation method of reasonable submergence when swabbing gas mixture crude oil[J]. Oil Drilling & Production Technology, 1995, 17 (5): 90 - 93.

[2] Yuguang Geng, Yunhui Zhai. Supply and discharge coordination diagram and application of rod pump pumping oil[J]. Oil Drilling & Production Technology, 1995, 17 (6) : 78 - 81, 107.
[3] Junhai Li, Tianzhong Wu. Determination method of reasonable submergence of rod pump[J]. Journal of Jianghan Petroleum Institute, 2001, 23 (2): 36 – 37.

[4] Qi Zhang. Principles and Design of Oil Recovery Engineering[M]. Dongying: China University of Petroleum Press, 2000: 103 - 117.

[5] Jinxia Fan, Jingli Duan, Xiaogang Jiang, etc. General Solution about the Crack Reasons of Top Cage of Plunger for Domestic and Overseas[J]. Oil field equipment, 2011, 40 (6): 26 - 29.

[6] Jianhua Rao, Zhaohong Liu, Dongping Li, etc. Dynamic numerical simulation and prediction of rod pumping system in directional well[J]. China petroleum machinery, 2004, 32 (8): 4 – 6.

[7] Lea J F. Boundary condition used with dynamic models of beam Pump Performance. Amoco Production Co. Southwesten Petroleum short Course [J].1988, 120-131.

[8] Jennings J W, Lame R E. A Method for design Fiberglass sucker rod string Using APRIL[J]. SPE18188, 1988, 44-78.

[9] Gibbs S G. A general method for predicting rod pumping system performance [J]. SPE685050, 1977, 1-8.

[10] Zhenwen Dong, Shengjie Dong, Dongfeng Lu, etc. Simulation models for optimization design of suction parameters for rod pumping system in directional wells[J]. Acta petrolei sinica, 2008, 29 (1): 120 – 123.

[11] Zhenwen Ni, Jun Qi, Jianhua Hao. Motor rotate speed control technology on the beam-pumping unit[J]. Oil field equipment, 2001, 30 (5): 46 – 49.