Research on Intelligent Energy-saving Algorithm of Oil Pumping Based on BP Neural Network

Tianshi Liu, Mengdi Shi
School of Computer Science, Xi’an Shiyou University, Xian 710065, China
13679206892@163.com

Abstract: In order to enhance the international competitiveness of China's oilfields, this paper reduce the phenomenon of high energy consumption in low-permeability oilfields, reduce electricity costs, increase oil production, and improve oilfield efficiency. In this paper, an intelligent energy-saving algorithm based on BP neural network is proposed for continuous oil recovery. This algorithm analyzes the main influencing factors of oil production and collects sample data from two aspects of oil production and electricity consumption cost. The BP neural network model with single hidden layer is constructed. The number of hidden layer neurons is determined. The output of oil and the unit speed of oil pumping are predicted, and combined with the time-sharing electricity price to adjust the times of oil pumping unit time to reduce the cost of electricity. The experimental results show that the proposed intelligent pumping energy-saving algorithm effectively improve the pumping efficiency, can save the electricity cost to a certain extent, realize the intelligent control of pumping unit, and makes the oil field achieve high production and efficiency.

1. Introduction
In the middle and later period of oilfield development, the formation pressure gradually decreased, the oil well's liquid supply capacity was insufficient, and the working state of the oil pumping unit did not match with the characteristics of the oil well, which led to the obvious decrease of the efficiency of the oil pumping system and the serious energy loss cause different degrees of "light load" or "no load" phenomenon, resulting in a huge waste of energy[1]. Therefore, how to improve the working efficiency of oil well is very important to the sustainable development of oil field. To solve this problem, many researchers put forward different methods to improve the efficiency of oil wells. In reference[2], the reasonable speed range of single well is obtained by using the method of preventing resonance speed setting, speed setting with favorable area setting, and the curve method of lifting efficiency. Reference[3] through deducing the calculation formula of annual liquid production under different production systems, it further improves the prediction accuracy of the variation law of oil field liquid production, and works out the best production system combined with oil field liquid production capacity. In 2009, Zhou cai-lan introduced the artificial neural network(Ann) into the prediction of oil industry, and put forward a BP neural network model to realize the accurate prediction of oil production[4]. In reference[5], the measures to improve the efficiency of mechanized mining system are discussed from the aspects of reasonable matching of motor, liquid yield and submergence degree. In 2017, Shao Dongbo and others studied the characteristics of the peripheral seepage flow and the effect of displacement efficiency in ultra-low permeability sandstone reservoir by using oil-water relative permeability and macroscopic model displacement experiments, and obtained the relationship between water cut and recovery factor[6].
Although the above measures have positive effect on oilfield production from different angles, they do not consider the influence factors of multiple production. Therefore, this paper presents an intelligent energy-saving algorithm for oil pumping based on BP neural network. The algorithm predicts the oil production and the oil speed according to many factors, and adjusts the time-of-use electricity price to maximize the oil field production benefit.

2. Influencing Factors of Oil Well Production Benefit

The influencing factors of oil well production include permeability, mobility, wash times, fluid production, water production, formation oil viscosity, water cut, start-up time, comprehensive compressibility, etc. Revenue from oil production, electricity consumption and other costs are the main factors affecting oilfield benefits, which can be expressed as follows:

$$\Pi = f\left(q, P_r, Ec, Oc\right) = q \times P_r - (Ec + Oc)$$  \hspace{1cm} (1)

In formula (1): $\Pi$ -- oil well benefit(yuan); $q$ -- Oil production(ton); $P_r$ -- Crude oil price(yuan / ton); $Ec$ -- Electricity consumption(yuan); $Oc$ -- other costs(yuan).

The objective of this paper is to reduce the unnecessary energy loss and maximize the efficiency of oil pumping on the premise of ensuring the production of oil well.

$$\Pi_{\text{max}} = \max \left[f\left(q, P_r, Ec, Oc\right)\right]$$

Taking into account that other costs are fixed and not affected by oil production, the benefits of oil pumping are equivalent to:

$$\Pi_{\text{max}} = \max \left[q \times P_r - (Ec + Oc)\right]$$  \hspace{1cm} (2)

2.1. Oil Production

The main influencing factors of oil yield are permeability, pumping speed, water content, start-up time and liquid yield.

Permeability($K$) is the total flow rate per unit area of a fluid of viscosity 1 per unit pressure gradient per unit time, per unit D. Duthie. The pumping speed are the number of up-and-down speed movements of the Piston of the oil pump per minute in the working cylinder. When the crank rotates clockwise, speed of the oil pumping unit is exactly equal to the number of turns per minute of the crank. Generally speaking, the distance between the Dead Center and the Dead Center of the polished rod is called pumping speed. The water cut of oil well refers to the mass percentage of water in the produced liquid of oil well[7]. Start-up time is the oil pumping unit start-up time length. Fluid production refers to the amount of fluid produced by an oil well per unit time.

2.2. Cost of Electricity

Generally speaking, each oil field different time period oil field electricity price is different. If you charge for n periods of time in a day, the consumption of electricity can be expressed as:

$$Ec = \sum_{i=1}^{n} T_i \cdot P_i \cdot E_i$$

$$= \sum_{i=1}^{n} \left(T_i \cdot 1000 \cdot I_i \cdot U \cdot E_i\right)$$

$$= 1000 \cdot U \cdot \sum_{i=1}^{n} \left(T_i \cdot I_i \cdot E_i\right)$$  \hspace{1cm} (4)

In formula (4): $T_i$ -Time Interval oil pumping unit operation time(H, hours); $P_i$ -time interval oil pumping unit power(Kw); $E_i$ -i time interval Electricity Price(yuan / Kw h); $I_i$ -i time interval oil pumping unit current(A, ampere); $U$ -Voltage(V, volt).
3. BP Neural Network

Back Propagation (BP) is a multi-layer feed-forward network trained by error Back Propagation Algorithm. It is one of the most widely used neural network models [8-9]. BP Network can learn and store a large number of Input-Output model mapping relationship, divided into two sub-processes: forward signal transmission sub-process and error signal transmission sub-process, including Input Layer, Hidden Layer and Output Layer. When the learning sample is provided to the network, the activation value of the neuron is transmitted from the input layer to the output layer, and the input response is obtained from the neurons in the output layer. Then, according to the direction of reducing the error between the expected output and the actual output, the connection weights are revised from the output layer through the middle hidden layers. Finally, back to the input layer, the accuracy of the network response to the input-output mode increases with the propagation correction of the error inverse. Each input-output sample pair in the training data set is repeated until the error of the data set is reduced to the required level.

In this paper, a three-layer BP neural network with a hidden layer is used to establish the prediction model. At present, there is no definite formula to determine the number of hidden layer neurons, the final determination of the number of neurons still needs to be based on experience and multiple experiments to determine. The following empirical formulas are used in the selection of hidden layer neurons:

\[ l = \sqrt{n + m + a} \] (5)

In formula (5): \( l \) -- Number of hidden layer neurons; \( n \) -- Number of input layer neurons; \( m \) -- number of output layer neurons; \( a \) -- constant between [1,10].

4. Energy Saving Algorithm for Oil Pumping

4.1. Algorithmic design

In this paper, the algorithm design is divided into two parts: the Neural Network prediction of oil pumping volume and initial value of oil pumping, and the time-sharing electricity price adjustment of oil well revenue maximum value. The sample data is used to build a network, to predict the oil production and the speed to calculate the initial value of the oil well returns, and then to adjust the speed by using the time-sharing electricity price. The final determination of a speed can maximize the oil well revenue, the speed is the best value. Compared with the initial value given randomly, the prediction result of neural network is closer to the optimal impulse times, which can shorten the operation period of time-of-use price adjustment.

To sum up, the energy-saving algorithm for oil pumping oil is:

Algorithm: Energy-saving algorithm for oil pumping
Input: Neural network sample data, The electricity price for the time period is \( E \)
Output: Pumping speed \( N \)
While (1)
If (time \( T \) period change)
step1: Initializing the number of training times for creating a neural network epochs=3000, convergence error goal=10\(^{-7}\)
step2: Neural network prediction of oil production \( q \) and pumping speed \( N \)
step2-1: do
step2-1-1: Modified number of hidden layer neurons \( l \in \{4,13\} \)
step2-1-2: Calculating training error
while training error<10\(^{-7}\)
step2-2: Prediction of oil production \( q \) and pumping speed \( N \)
Else
step3: Calculation based on neural network prediction results \( \Pi(N) = P \cdot q(N) - 1000 \cdot T \cdot I(N) \cdot U \cdot E \)
step4: Time-sharing electricity price adjustment pumping speed \( N \)
If (\( \Pi(N+1) > \Pi(N) \)) \( N++ \)
4.2. Algorithmic simulation

(1) Data sampling

The speed of a well is 1.8 meters, the pump diameter is 32 millimeters, the pump depth is 1083 meters. This paper analyzes the factors affecting oil production of oil well, and constructs 200 sets of sample data, which include: liquid production, oil production, water production, water cut, starting time 24 hours, permeability, punching times. Some of the sample data is shown in Table1.

| Liquid production(t) | Rate of water content(%) | Water yield(t) | Penetration ($\times 10^{-3}$D) | Oil production(t) | Punch (times/min) |
|----------------------|--------------------------|---------------|---------------------------------|-------------------|-------------------|
| 8.66                 | 61.9                     | 5.36          | 14.3                            | 2.77              | 5                 |
| 5.45                 | 65.5                     | 3.57          | 14.3                            | 1.58              | 4                 |
| 5.22                 | 54.5                     | 2.84          | 14.3                            | 2.00              | 4                 |
| 7.21                 | 50.4                     | 3.63          | 14.3                            | 3.00              | 4                 |
| 9.32                 | 53.0                     | 4.94          | 14.2                            | 3.68              | 5                 |

(2) Network Creation

According to the reference formula(5) of the data item of the sample, the number of input neurons 5 and the number of output neurons 2 can be determined, then the optimal number of hidden layers should be between 4 and 13, from the minimum number of neurons 4 to the maximum number of neurons 13 The expected error goal=$10^{-7}$ is as shown in Table2. After comparing the different training error corresponding to the number of neurons in different hidden layers, the number of neurons in hidden layers with minimum error 8 is finally selected.

| Hidden layer cell number | Training error |
|--------------------------|----------------|
| 4                        | 9.939e-08      |
| 5                        | 6.392e-06      |
| 6                        | 7.365e-08      |
| 7                        | 9.916e-08      |
| 8                        | 3.323e-09      |
| 9                        | 7.692e-05      |
| 10                       | 1.958e-08      |
| 11                       | 7.756e-08      |
| 12                       | 9.369e-08      |
| 13                       | 9.241e-08      |

(3) Network training and forecasting

The output of fluid, the output of water, the water content, the start-up time, the permeability were taken as the input data of the neural network, the output data were taken as the output data, and the first 170 groups were taken as the training data simulation The last 30 groups were used as the test data to get the predicted oil yield and the predicted pumping speed. Using the network prediction performance of one oil production and one oil speed as an example, the predicted oil production and the actual oil production of 30 groups of data are summarized as follows: figure 2, the predicted oil production and the actual oil production are summarized as follows figure 3.
Benefit comparison

Taking into account the time-sharing nature of the oil-field Electricity Price, according to formula(4), the electricity consumption cost of the oil-pumping energy-saving algorithm can be calculated, and the speed can be appropriately reduced during the peak period of the electricity price, and the speed can be appropriately increased during the peak period of the electricity price, which affects the rotation speed of the motor Which in turn affects motor power.

According to the benefit model(3), calculate the oil well benefit of the traditional oil pumping mode:

$$\Pi_{ori} = q \cdot P_i - P \cdot E$$  \hspace{1cm} (6)

Time-of-use electricity price adjustment pumping speed, current and the speed is proportional to each other, affecting the oil pumping unit power. Replace(4) formula with benefit model(3) to calculate the benefit of energy-saving algorithm.

$$\Pi_{new} = P_i \cdot \sum_{r=1}^{n} q_i - 1000 \cdot U \cdot \sum_{r=1}^{n} (T_i \cdot I \cdot E_i)$$  \hspace{1cm} (7)

According to the latest statistics, the international average price of crude oil is 53 US dollars per barrel(28/1/2019). According to the standard of 0.85 barrels per ton, the current price of crude oil is $53 \times 6.8961 \times 0.85 = 310.7$ yuan per ton.

Energy-saving algorithm oil pumping algorithm take an oil field as an example, the oil field electricity charge is divided into three stages:

1) 8:00-11:00, 18:00-21:00, 0.9 yuan per kilowatt hour.
2) 7:00-8:00, 11:00-18:00, 0.56 yuan per kilowatt hour.
3) 21:00-7:00, 0.23 yuan per kilowatt-hour.

The average power of the traditional oil pumping mode is 20kw H, the average charge is 0.51 yuan per kilowatt hour, and the plug-in type(6) is used to calculate the annual revenue of the traditional oil pumping mode. In the energy-saving algorithm, the maximum power of 35KW and the minimum power of 15KW are set after the time-sharing price adjustment, the predicted oil production is extracted from
30 groups of prediction data, and the substitution (8) is used to calculate the annual revenue of the energy-saving algorithm. Comparing the two methods, the benefit analysis is as follows table 3.

|                                | Annual oil Production(t) | Annual electricity consumption cost(yuan) | Annual earnings(yuan) |
|--------------------------------|--------------------------|------------------------------------------|-----------------------|
| Traditional oil pumping income | 1,098,650.0              | 134,028,000.0                           | 207,322,555.0         |
| Energy saving algorithm oil   | 1,299,400.0              | 99,827,500.0                            | 303,896,080.0         |
| pumping mode income          |                          |                                          |                       |
| Rate of rise                 | 18.3%                    | -25.5%                                   | 46.5%                 |

5. Conclusion
Compared with the traditional oil pumping method, the algorithm proposed in this paper has significantly improved the income of the former, and has made the oilfield energy saving and production significantly improved. The application of the algorithm breaks through the traditional pumping method to make the oilfield control more intelligent and has a strong application value.

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