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Towards Pumping Unit Energy-saving: a Fuzzy Networks Approach

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Abstract: This study firstly defines a resource waste problem of oil exploration. It combines the interval pumping mechanism and fuzzy neural network algorithm to forecast the amount of liquid pumping capacity. Then it determines the reasonable interval time for the pumping unit by comparing the predicted liquid production and the standard liquid production. The algorithm simulates by Matlab to verify the accuracy of its economic value. The experimental results show that the energy-saving algorithm reduces the energy consumption and increases the profit sharply.

Key words: Pumping unit, energy-saving algorithm, interval pumping, fuzzy neural network, production efficiency

INTRODUCTION

With the development of global industry, the economy of China grows rapidly. However, the reserves of all kind of resources are reducing seriously day after day. Energy saving has become a worldwide problem. For instance, light load or no-live load has become a common phenomenon on the oil field which has caused a vast waste of resources, especially the electricity. The electricity consumption accounts for a sizable proportion of the whole cost for oil exploitation (Zhang and Yu, 2006). It has become one of the hot issues to reduce the energy consumption effectively and to improve the efficiency of electricity on the pumping unit (Chen *et al*., 2012).

Interval pumping mechanism (Qin, 2012) has been used in the actual production on the majority of oil fields. It is mainly aims at the inefficient wells (Including low-yielding liquid wells, low pump efficiency wells and low flow pressure wells) (Yu *et al*., 2006).

Due to the insufficient capacity of fluid underground, the fluid levels of each pumping unit do not drawdown and recover in the same time. Therefore, the interval pumping mechanisms are different. It is with a very real sense to find a reasonable interval pumping mechanism for the oil field (You, 2011). Traditional interval pumping mechanism was discovered through a period of exploration and manually starts and stops the pumping unit by experience from experienced engineers. But, manual control has low accuracy and staffs are overload. This study proposes an energy-saving algorithm for pumping unit based on the Fuzzy Neural Networks (FNN) (Lin *et al*., 2010) to control the pumping unit starting and stopping automatically.

ENERGY-SAVING ALGORITHM

FNN was based on Neural Networks (NN) (Biswajeet and Saied, 2010) and Fuzzy System (FS) (Zhang *et al*., 2000). So that it fully considered the complementarities (Wang, 2007) between NN and FS. The fuzzy concept and the fuzzy inference rules were introduced into neurons of NN, connection weights and network learning on the consideration of improving the enlightening, transparency and robustness of NN.

FNN can be applied to estimation, such as estimate software development effort (Huang and Chiu, 2009). FS has been used in hybrid neural network which called the self-organizing fuzzy neural network (SOFNN), to extract fuzzy rules from the training data. Simulations show that the SOFNN has the capability to encode fuzzy rules in the resulting network (Leng *et al*., 2005). NN model has been used to bridge the historical gap between dynamic and structural approaches to personality (Read *et al*., 2010).

Fuzzy neural network algorithm which used by this study can predict the future liquid volume production in accordance with prior liquid production by training the NN. Every pumping time of this study is constant. The interval time has been set an initial value and then it would be adjusted according to the predicted liquid production. The next boot would be determined by the comparison of predicted liquid production with its standard output. The standard output is determined by pump diameter, stroke, jig frequency, average pumping efficiency and the running time of each boot. Standard output is calculated as the following equation:

$$SO = RTOEB \times 60 \times \frac{\pi \times PD^2}{4} \times S \times JF \times PF$$

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where, SO is the standard output, RTOEB is the running time of each boot, PD is the pump diameter, S is the stroke, JF is the jig frequency and PF is the pump efficiency.

Measurement of running time, diameter of the pump, stroke and jig frequency are hour, millimeter, meter and time, respectively.

DESIGN OF ALGORITHM

Assume T_w represents the running time of each boot, T is the interval time, S is the stroke, N is the jig frequency, D signifies the pump diameter, λ is the average value of pumping efficiency, P_s is the standard production of each T_w. is the predicted production of new. Following steps depicts the calculation of P_s:

$$P_s = T_w \times 60 \times \frac{\pi \times D^2}{4} \times S \times N \times \lambda$$

The design process of the algorithm is as following:

Step 1: Set the initial value
Step 2: Calculate the standard liquid production
Step 3: Choose the sample data
Step 4: Train the neural network
Step 5: Forecast the future liquid production and determine the interval time. If $P_f<P_s$, then:

$$T = T\times(1+(P_s-P_f)/P_s)$$

else:

$$T = T\times(1+(P_f-P_s)/P_s)$$

Step 6: Add the newly forecasted data to the sample data
Step 7: Repeat from step 4

EXPERIMENT

Data sampling: The raw data is not suitable for the experiment. It should be transformed for the calculation. Meanwhile, the data source is secret.

For verification of the algorithm, we have sampled 150 rows of well log data. Table 1 shows the first 5 data rows of one well. Such well has the stroke of 1.8 m, jig frequency of 5, pump diameter of 32 mm, the depth of which is 1083.67 m. The initial interval time is 4 h; the running time of each boot is 24 h.

Simulation:

- **Data extraction:** Load the sample data; point out the input and the output

Table 1: Sample data

Liquid production	Oil production	Water production	Moisture content	Running time of each boot	Interval time
6.57	2.68	3.38	51.5	24	4
7.21	3.00	3.63	50.4	24	4
9.32	3.68	4.94	53.0	24	4
5.21	1.65	3.25	62.3	24	4
8.32	2.41	5.45	65.5	24	4

Table 2: Training parameters

Training times	Inertia coefficient	Learning rate
200	0.001	0.05

- **Construction of network:** Generally, FNN is divided into three layers, input layer, hidden layer and output layer. The neural network must be constructed before the simulation. The construction includes setting the number of neurons for each layer, training function, network coefficient and the initialization of parameters
- **Network training:** Network training is a constantly process revising internal link weights and thresholds of neural networks. The output error of network would be the minimum and meet the requirements of practical application by adjustment. Training parameters are set as the (Table 2)
- **Network forecast:** Network has a skill of memory. It would learn the pumping law through training and then it would forecast the liquid production. Finally, the reasonable interval time for the pumping unit comes from the comparison of the predicted liquid production and the standard liquid production

ANALYSIS OF EXPERIMENTAL RESULTS

Figure 1 shows the simulation results by MATLAB.

As can be seen from the Fig. 1, the error between the predicted and actual fluid production is absolutely small.

Then we compared the predicted fluid production and standard fluid production and calculated the difference. Next, we adjusted the interval time according to the difference. Figure 2 shows the new interval time.

As can be seen from the Fig. 2, the overall trend of the pumping time is decreasing. It indicates the current output of oil well is abundant which can be supplied for the basic operation. So, the interval time can be shorter. The more abundant the oil is, the shorter the interval time is. The pumping unit will be on all the time in the ideal case. On the contrary, if the amount of the oil is insufficient, the interval time will increase relatively to ensure the bottom level can be recover to an appropriate degree after a certain period. Therefore, the pump unit will not be light load or no-live load which can reduce the consumption of the electricity and machine.

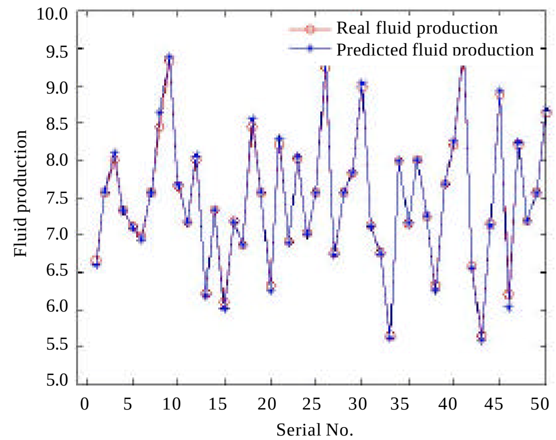

Fig. 1: Comparison between predicted fluid production and real production

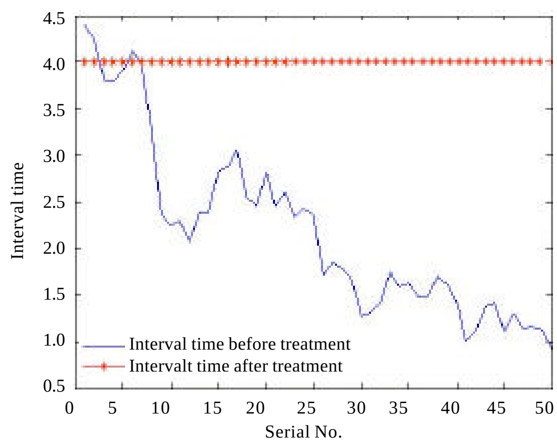

Fig. 2: New interval time

BENEFIT ANALYSIS

From annual oil production, annual electricity consumption, annual power consumption costs, annual benefit to compare the energy-saving algorithm with the traditional method.

It can be seen from the Table 3 that the energy-saving algorithm is better than the traditional manually controlled interval pumping mechanism. Annual oil production decreases about 69.6%, Annual electricity consumption reduces approximately 8.4%. Annual power consumption costs cut down about 8.4%. Finally, the total annual benefit increases about 1.5% of the traditional manually controlled interval pumping mechanism.

Following is the calculation of benefit:

$$\text{Benefit} = \text{oil production}\times\text{price cost}$$

Table 3: Comparison between the results of traditional method and energy-saving algorithm

	Traditional method	Energy-saving algorithm
Annual oil production (T)	2986065	2965260
Annual electric consumption (KWh)	657000000	601702500
Annual power consumption costs (RMB)	335070000	306868275
Annual benefit (RMB)	1161784663	1179557258

where, the benefit is mainly depending on oil production, price and cost. Though the annual oil production of the energy-saving algorithm reduces, the benefit increases. The cost saving is greater than the economic benefit which can be brought by the reduced portion of oil production.

CONCLUSION

This study proposes an energy-saving algorithm based on FNN to reduce the resource consumption on the oil field. Compared with the traditional pumping law, the production efficiency increases, the manual workload reduces and the accuracy of the work increases ultimately by using the energy-saving algorithm. In the future, this study can combine with a variety of sensors in order to achieve the ability to collect and analyze forecasts automatically. What is more, intelligent devices can be applied to this study for the integration of collection, forecast and adjustment.

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