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The Method of Energy Saving in Beam Pumping Unit Based on Genetic Algorithm

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Abstract

The load of beam pumping unit is changeable, which is often in a state of light load. Reducing a certain voltage can improve the power factor and efficiency of the beam pumping unit when in light load .We can change the voltage by changing the thyristor trigger angle. It is complex and unacceptable to analyze the change of the cycles of the load overall. So we can divide the load of the whole cycle into several equal parts, each can be thought of as a constant load. The most optimal voltage for the current load can be calculated by genetic algorithm. When each load is in the most optimal voltage, we can get the whole optimal voltage changeable rule. Then it produces the result of energy saving.

Keywords-load sharing; energy-saving by step-down; pulsed thyristor trigger; genetic algorithm; local optimum

1. Introduction

In petroleum exploitation, the beam pumping unit is used widely. But the phenomenon “big marathi car” exists [1], which is caused by the reasons that in order to satisfy the start requirements of pumping unit and ensure sufficient overload capacity. So eventually it enhances the efficiency of electric motor of the unit, and

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causes the pumping unit often works in light load. People have developed many kinds of energy-saving beam pumping unit at home and abroad. What's more, the technology of power factor correction, soft start, adjustable speed motor, thyristor voltage regulator has appeared in the sphere of saving energy control beam pumping unit studying. The current energy-saving device is mainly solving the energy saving problems form two aspects. One is for power factor compensation. But the main problem of this kind of method is the cost of device is high. The other is for voltage control by thyristor. And its main problem is the low efficiency [2]. Especially for the equipment whose load is constantly changing, the efficiency will be even lower, taking the beam pumping unit for example. Because the current energy-saving device does not completely solve the problem of high equipment costs and low efficiency, this paper proposes an energy-saving device which is based on genetic algorithm. It comprehensive utilizes the theory of energy-saving by step-down, adjustable voltage by thyristor and genetic algorithm.

2. The Design Of Energy-saving Device

It is complex and unacceptable to analyze the change of the cycles of the load overall. So we can divide the load of the whole cycle into several equal parts, each can be thought of as a constant load. We can change the voltage of motor by changing the thyristor trigger angle in each half cycle. According to the theory of genetic algorithm, we put the thyristor trigger angle as individual in the genetic algorithm. The individual in the genetic algorithm is corresponding to voltage when the voltage is corresponding to the power factor of the beam pumping unit .And the power factor can be measured through a certain device. So what the theory of genetic algorithm needs can be gotten. After a period of operations for choosing and crossover, we can get the optimal voltage in each of the constant load, which can make beam pumping unit run under the status of high efficiency and energy-saving

Energy-saving device can be divided into the following parts:

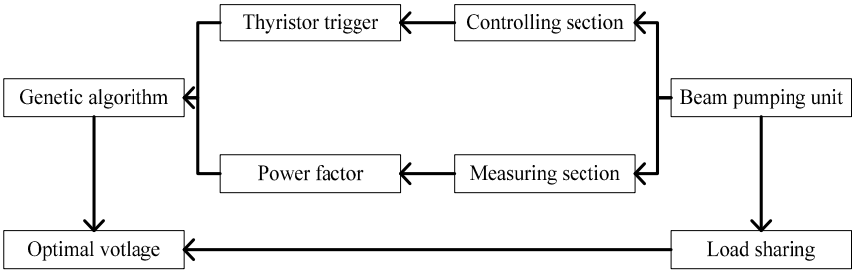

Fig .1. the principle of energy-saving of the beam pumping unit.

2.1. Load sharing

The oil well pump can be driven by AC motor, which moves back and forth along the direction of gravity. Then it can take the oil from hundreds to thousands of meters underground to the ground. In addition, the load is cyclic and the character and size of the load are different when up and down. Nowadays, there are many articles analyzing and controlling the cycles of the load overall. The advantage of this method is that we can get the aim of improving the power factor and the efficiency of the beam pumping unit through simply reducing or raising the voltage of motor. But the major problem is that it can only raise a small amount of power factor and efficiency, because this kind of method treats the different character and size of the load as equal. So this method is unreasonable. We can get the conclusion that it is complex and unacceptable to analyze the cycles of the load overall. In this paper we divide the whole cyclic load into several equal parts,

and then we analyze each part. The advantage of this method is that each load just change a little and each can be analyzed as a constant load.

2.2. Energy-saving by step-down

There are two main reasons that cause the loss in the motor of the beam pumping unit .The first is reactive power consumption of the motor. The second includes stator copper loss, rotor iron loss and rotor copper loss of the motor. The main method to solve the first kind of loss is reactive power compensation for beam pumping unit. The method of compensating reactive power is introduced to raise the power factor of electric equipment, such as use parallel capacitors. The result of this method is good, but its shortcoming is that the design of devices for power factor compensation control system is complex. Because the second kind of loss is directly related to the voltage[3], so the main method to solve this problem is reducing loss by reducing the voltage when the beam pumping unit is in light load or no load. Generally speaking, the ratio of iron loss is much larger than the copper loss when in light load, so at this time reducing the voltage can reduce the motor loss and improve the power factor.

The power factor of the motor is related to many factors. It mainly includes load current, voltage and slip. We can get the expression of the relationship between the power factor and the other factors:

$$\cos\phi = r_2 I_2 /(sE_2) \approx I_1 / U \qquad (1)$$

r_2 is rotor resistance. s represents slip, I_2, which depends on load current, represents rotor current. I_1 represents stator current, which is made up of I_2 and I_0. I_0 represents excitation current. E_2 represents rotor voltage, which has the approximate same size with the stator voltage U. Obviously, because I_0 does not change when the load changes, so whether the size of I_1 change or not will depend on the load. When the load is low, the power factor angle is big while the power factor is small. When the load increases, the current I_2 and I_1 will increase and the power factor will also increase. From formula (1) we can get the conclusion: When the load does not change, which means that the slip will not change, the rotor current will keep the same and the more the voltage, the less the power factor. Therefore, we have to reduce the voltage U if we want to have a high power factor when the motor is in light load, which means that we can increase the power factor if we reduce the voltage.

2.3. Thyristor control

The thyristor has played an important role in the area of power electronics since it was born. It is widely used in the sphere of power and AC or DC voltage regulation as its excellent price-performance ratio and large capacity, which can not be compared with by the other devices. The thristor can be used to form a switch with its special character. We can control the high voltage and high current circuit on and off when we control the gate current. Bi-directional thristor is the mainly derivative component of the thristor series, which can take place of a set of general anti-parallel thyristor in AC circuit. So it is a kind of ideal AC power control component. In order to make the pipe pass the AC current, a gate trigger signal must be sent within each half cycle [4]. The component can continue to conduct only when the current is greater than the trigger current while the component can shut off only when the current is smaller than the maintainable current.

In the process of designing energy saving component we make use of thyristor to control voltage. The size of voltage depends on the thyristor trigger angle. In the following when we make use of the theory of genetic algorithm, we put the thyristor trigger angle as individual in the genetic algorithm.

2.4. Measuring section

We need to know the size of power factor all the time, which can be directly measured by certain equipment. There are many kinds of methods to measure the size of power factor. In this paper we choose a simple one, whose main principle is that we get the power factor through measuring the phase difference between phase voltage and phase current. The basic principle is shown in figure 2:

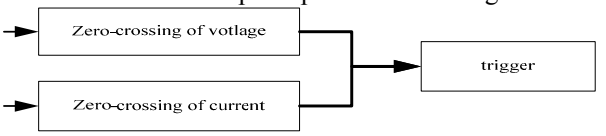

Fig. 2.the principle of measuring the power factor

We can change the phase voltage and phase current into square wave through the component of zero-crossing, and the square wave will be the input of the trigger [5]. The output of the trigger is the phase difference between phase voltage and phase current. Because the frequency of the phase voltage and current is 50Hz, which corresponds to cycle for 20000 μ s, and one cycle is equal to angle for 360 degree, so we can calculate the size of the power factor if the phase difference is measured. The formula is as follows:

$$\phi / T = 360 / 20000 \qquad (2)$$

Power factor cos ϕ can be calculated through formula (2).

2.5. The application of genetic algorithm

Genetic algorithm is a kind of global optimal search algorithm based on theory of evolution and heredity. Through encoding the parameter space and adopting the changeable rules of probability the genetic algorithm makes the process of searching become more efficient [6]. Compared with traditional optimistic algorithm, we can get better result by making use of genetic algorithm for optimal probability research . The thyristor trigger angle of the current load is the individual function of the genetic algorithm while the power factor which has been measured is evaluation function of the genetic algorithm. The optimal trigger angle can be gotten by applying the theory of the choosing, crossing and variation. Every part has an optimal voltage, and the result will be optimum. The process of the algorithm is as follows:

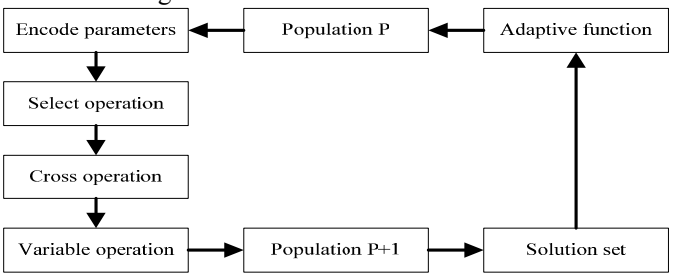

Fig. 3.the key process of genetic algorithm

2.5.1. Encode all parameters

In order to make the pipe pass the AC current, a gate trigger signal must be sent within each half cycle. The parameters which need be encoded are the trigger angle α_1 of the first-half cycle and the trigger angle α_2 of the second-half cycle. Every trigger angle will be translated into a p-bit binary string as follows:

$$\alpha = \alpha_{\min} + [\alpha(i)/(2^p - 1)][\alpha_{\max} - \alpha_{\min}] \quad (3)$$

α(i) is a binary digit which is represented by p-bit string. The maximum of trigger angle's degree is 180 degree, and the minimum is 0 degree. The two trigger angles can be represented by 10-bit binary string in application. The individual whose length is 20 bits is made up of two trigger angles.

2.5.2. Population of initialization

The total number of the individuals of every generation has a big effect on the efficiency and the final result of genetic algorithm. When in small scale, the algorithm may converge to a local optimum and it can not get the best result. And if it is in large scale the calculation will be very complex and it will be a waste of time to solve it. Based on a large amount of research and experiment the best scale range that we can get is from 30 to 110. In early stage the motor can run 30 to 110 cycles randomly. It means that the thyristor trigger angle is a random number from 0 to 180. So we can get the initial population.

2.5.3. Adaptive function

When genetic algorithm operates, it depends on the size of adaptive function .Then it evaluates the group. In this paper the size of adaptive function which corresponds to the power factor of the motor can be gotten through measuring rather than calculate.

2.5.4. Select operation

Select algorithm completes its operation according to the adaptability of the individuals. We can use the method of select sort whose size is ordered from big to small according to the degree of the individuals' adaptability. Then we can ensure the probability whether the individuals will be selected. Treat the probability that the individuals assigned as the one they will be selected and then use the proportional sort to produce the next generation.

2.5.5. Cross operation

Cross operation imitates the process of biological chromosome pairing, which is also the major means to produce the new individual. The process of cross operation is that the two mutual paired individuals can produce two new individuals according to some set way and a certain genetic value in partial genes which exchange the individual coding series based on cross probability. The method of designing the cross operator is various in different situation. The principle of cross operation is that when the new individual is produced we should try to maintain the individual coding mode..

2.5.6. Variable operation

The variable operation of genetic algorithm imitates the variation in the process of biological heredity and evolution. It completes its operation by changing the genetic value of partial genes in individual coding series which has been chosen. Then it creates a new individual and increases the diversity of population. The main function of variable operator in genetic algorithm is to improve the algorithm's local research capability.

2.5.7. Stop operating

There are two main conditions that can stop the operation. One is to find the optimal solution; the other is to reach the termination of algebra. After reaching the termination of algebra, genetic algorithm will stop all the operation and output the best current individual in the population as the optimal solution.

3. Summary

By using the genetic algorithm we can calculate the optimal voltage of each load. The beam pumping unit can improve the power factor and the efficiency of motor significantly under the optimal voltage. The figure of power factor can be shown as follows:

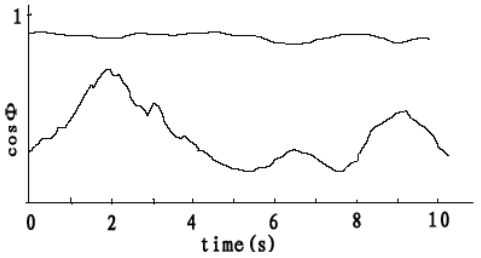

Fig. 4.the power factor of beam

Curves in the figure represent the power factor of beam type pumping unit when operates in different voltage. From the under curve which represents the beam type pumping unit operates under constant voltage we can see different load rate has different power factor. When the load rate changes violently the power factor also changes violently. The above curve which represents the beam type pumping unit operates under optimal voltage has obvious improvement comparing with the under one. Then it reaches the aim of energy-saving.

Acknowledgements

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