Intelligent Control Strategy and Proposed Motor Drive Operating Mechanism for High Voltage Disconnecting Switch

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Abstract

A new type of operating system (motor drive) is introduced to remedy the following typical shortcomings shared by high-voltage Disconnecting Switch ("DS") operating mechanisms in this paper: 1) poor controllability, 2) failure to meet requirements of opening and closing speeds, and 3) closing bounce. The current and speed dual-loop control method was used in the DS operating mechanism control system. Due to the motor operating mechanism control system's nonlinearity, the control error is large when the conventional double-loop PID control system was used. The fuzzy control algorithm combined with the PID controller can adjust the control parameters online and enhance its control capability of nonlinear control system – thereby reducing control error. Experiment results show that combined with fuzzy control algorithm of motor operating mechanism, intelligent control system can make real-time adjust the speed of switch contact to ensure the motion of stability and meet opening and closing speed requirements.

Keyword: BLDCM, fuzzy control algorithm, High Voltage disconnecting switches, operating mechanism, PID

1 Introduction

The operating mechanism of DS in the working process often due to the fast or slow speed caused opening rejected or closing rejected, contact does not reach the designated position and the driving part deformation failure[1]. Therefore, it is necessary to control the motion process of the switch contact. Previous high-voltage Disconnecting Switch ("DS") operating mechanisms share the same shortcomings of connecting rod and complex structure whether they use spring, hydraulic or pneumatic technology. They all have difficulty realizing movement control of the contact with its cumulative exercise tolerance large, slow response, and poor controllability [2].

Motor operating mechanisms controlled by power electronic devices are drive DS opening and closing operation with the advantage of few moving parts and stable operation. In this paper, the brushless dc motor (BLDCM) operating mechanism is put forward on the basis of high voltage circuit breaker motor operating mechanism research, and the speed control system is designed [3-4] resulting in the DS contact in the movement process gaining good controllability, improving its opening and closing reliability, and reducing operating failure and reduce contact collision. At the same time, current and speed double closed loop control strategy is used to control the movement process of the contact, and the algorithm of fuzzy control is used in the speed loop control. Fuzzy control algorithm combined with PID can adjust, in real-time, the control parameters of the controller. The control precision of the motor has improved, and the switch contact action stability has a large ascension.

1.1 TRAVEL REDUCTION OF DISCONNECTING SWITCH CONTACT

GIS DS operating mechanism structure diagram as shown in Fig.1.

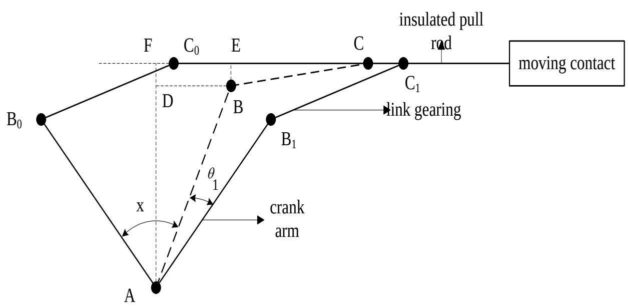

FIGURE 1 DS drive mechanism structure diagram

Using moving-contact on opening position, the corresponding position of the drive motor at AB0 is indicating for the initial position of calculating. The motor rotates 80°, eventually moving-contact move to the closing location, and the drive motor corresponding at AB1 for the end position of calculating. The rotation process was divided evenly into many small corners, and then calculated the space position of the transmission parts successsively under different angles. The moving distance of moving-contact can be calculated. In the rotary process of motor, the relationship of space position for all the moving parts was shown on the type (1) :

$$\begin{cases} \theta_{BAD} = \theta_a - 40^\circ \\ AD = AB\cos(\theta_{BAD}) \\ BD = AB\sin(\theta_{BAD}) \\ BE = AF - AD \\ CE = \sqrt{BC^2 - BE^2} \\ CF = CE + BD \\ CC_0 = CE + EF - C_0F \end{cases}, \quad (1)$$

where θ_a as a drive motor angle in real time.

Calculate the movement process of the DS motor operating mechanism, the contact trip with the motor angle can be got as shown in Fig.2.

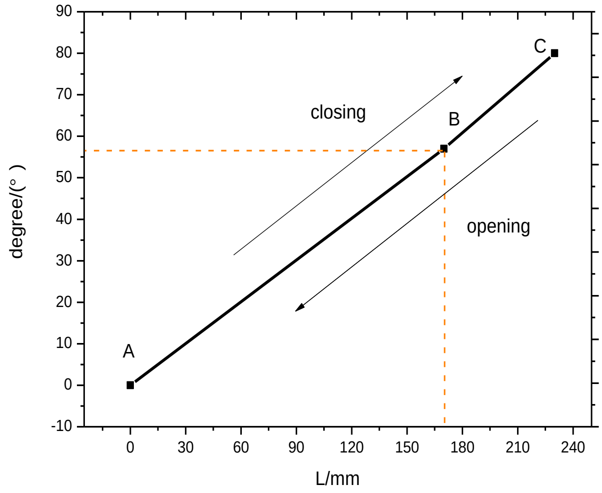

FIGURE 2 Contact travel and motor rotation curve

Motor drive DS contacts in the stage of travel, the equivalent load counterforce of the friction f_1 acting on point A is:

$$F_1 = f_1 \cos\arcsin\frac{c - a\cos(x-40)}{b}\cos[|x-40| + \arcsin\frac{c-a\cos(x-40)}{b}] \quad (2)$$

In the over travel stage, the equivalent load counterforce of combined forces f_1 and f_2 at A point is:

$$F_2 = (f_1 + f_2)\cos\arcsin\frac{c - a\cos(x-40)}{b}\cos[|x-40| + \arcsin\frac{c-a\cos(x-40)}{b}] \quad (3)$$

Through calculation, the load torque and motor rotation relationship is shown in Fig.3.

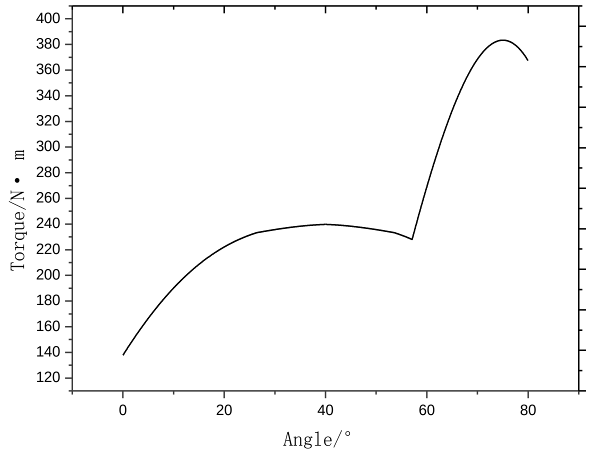

FIGURE 3 The relationship between load torque and motor rotation

1.2 ANALYSIS OF THE BLDCM MATHEMATICAL MODEL AND IT'S CONTROLLABILITY

According to the GIS DS operation process and performance requirements, permanent magnet brushless dc motor as drive motor is selected in this paper. Three-phase BLDCM winding voltage balance equation can be represented as [5]:

$$\begin{pmatrix} u_a \\ u_b \\ u_c \end{pmatrix} = \begin{pmatrix} r & 0 & 0 \\ 0 & r & 0 \\ 0 & 0 & r \end{pmatrix}\begin{pmatrix} i_a \\ i_b \\ i_c \end{pmatrix} + p\begin{pmatrix} L-M & 0 & 0 \\ 0 & L-M & 0 \\ 0 & 0 & L-M \end{pmatrix}\begin{pmatrix} i_a \\ i_b \\ i_c \end{pmatrix} + \begin{pmatrix} e_a \\ e_b \\ e_c \end{pmatrix} \quad (4)$$

According to the brushless dc motor theory knowledge, the following equation can be get.

$$U_d = E + I_d R_\Sigma + 2\Delta U \quad (5)$$

$$E = C_e \phi n \quad (6)$$

$$M_T = C_T \phi I_d \quad (7)$$

where u_a, u_b, u_c is voltage of the stator phase winding, i_a, i_b, i_c is current of the stator phase winding, e_a, e_a, e_a is electromotive force of the stator phase winding, L is inductance of each phase winding, M is mutual inductance between each phase winding, p is differential operator, $p = d/dt$, U_d is terminal voltage of two phase winding, E is counter electromotive force of brushless dc motor, R_Σ is Resistance of the stator armature, I_d is current of the stator armature, ΔU is tube voltage drop, C_e is brushless dc motor internal electromotive force constant, C_T is torque constant of brushless dc motor internal, ϕ is Brushless dc motor flux, M_T is The motor output torque. Comprehensive formula 4, 5, 6, brushless dc motor speed equation can get:

$$n = \frac{U_d - I_d R_\Sigma - 2\Delta U}{C_e \phi} \tag{8}$$

According to its mathematical model analysis, in order to be able to control motor speed, should put a variable voltage at both ends of the winding[6], in this paper the pulse width modulation (PWM) technique was taken to obtain variable voltage.

The driving force of DS is provided by DC motor, so the speed of DS contact is adjusted by changing the PWM duty ratios. Different PWM duty ratio is corresponded to different speed. As shown in Fig.4, from left to right in turn for the curves of motor movement displacement under the duty ratio is, 90%, 75% and 60%. So through the real-time change of PWM duty ratio can be realized to control the motor speed, then realize the switch contacts movement speed regulation control of the process, make sure that the stability of DS switching.

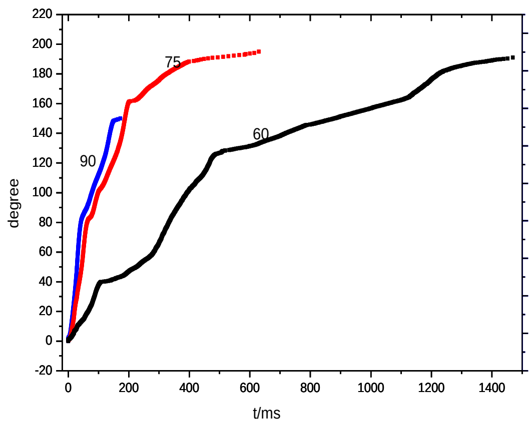

FIGURE 4 Travel curve of contacts under different duty cycle

2 Design of DS intelligent control system

2.1 MATHEMATICAL FOUNDATION OF FUZZY CONTROL

Fuzzy set theory is an extension of the classical set theory, in the fuzzy set theory, an element can be partly belong to a fuzzy set, and can be partially belongs to another fuzzy set. Due to the fuzzy set is no clear boundary, can only use membership function to represent the degree of a element belongs to a collection. Specific definition is as follows:

Set the domain U, μ_A is that U to the closed interval [0, 1] any mapping:

$$\mu_A : U \longrightarrow [0,\ 1] \\ X \longrightarrow \mu_A(x) \tag{9}$$

It can be determined a fuzzy set A of U, μ_A called fuzzy set membership function of A. The fuzzy set and its membership function one to one correspondence, the operation of fuzzy set can be described by membership function [7-8].

The correlation degree of elements is described by fuzzy relations. The definition of common set in relation to the fuzzy set, the definition of fuzzy relation can be got. To define the fields A and B , and the new domain A×B can get by direct product of A and B, the fuzzy relation R of A and B is a fuzzy set which is defined on the direct product of A ×B. It put on the each element (a, b) of the domain mapping between 0 and 1 membership degree, namely

$$R = \{((a,b), \mu_R(a,b)) | (a,b) \in A \times B\} \tag{10}$$

In the formula, membership $\mu_A(a,b)$ express sequence pair (a, b) associated with the degree of R, when A= B, R is called fuzzy relation of A.

The core part of fuzzy control system (see Fig.5) is the fuzzy controller. The control rules are implemented by the software program. Computer gets an accurate value of controlled volume by sample interruption, and then compared with the given value to get error signal E as an input of the fuzzy controller. The error signal E to dis-fuzzy mode into fuzzy one. Fuzzy variable is expressed in fuzzy language, it can got a subset e of the set of fuzzy language E of the error signal E, and then e and fuzzy control rules R according to the synthesis reasoning rules to fuzzy decision and fuzzy control variables u can be get assumed as:

$$u = e \bullet R \tag{11}$$

In order to realize exert precise control on the object, it need to transform the fuzzy variable u clarifications to clear value. Digital control by D/A transformation into analog, then send to operating mechanism, to realize the precise control of the controlled object.

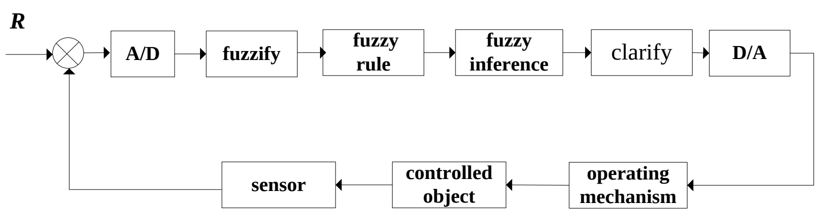

FIGURE 5 Fuzzy control system block diagram

2.2 ESTABLISH CONTROL SYSTEM AND FUZZY RULES

The digital double closed loop control was used in the motor operating mechanism control device, The connection drawing of control system and motor operating mechanism as shown in Fig.6, the inner of control system is current loop, adjust the output current by PID control algorithm. Outer loop is speed loop for motor speed regulating. In order to ensure that the whole system has good dynamic and static characteristic, speed loop adopts fuzzy PID control algorithm [9].

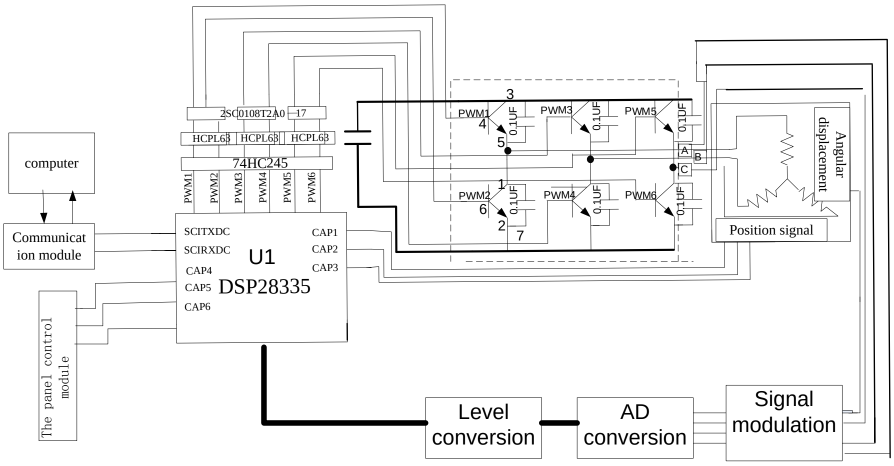

FIGURE 6 The connection drawing of control system and motor operating mechanism

According to the influence of parameters k_p, k_i, k_d to the system output characteristics and the performance of the DS contacts movement, can be obtained parameter self-tuning principle of the different e and ec. In the whole operation process through continuous testing e and ec ,and then according to the principle of fuzzy control on-line modification of three parameters, to meet the different requirements that different e and ec to the control parameters, and make motor to the preset reference curve has a good real-time tracking performance.

1) When $|e|$ is very big, In order to achieve rapid adjusting error, and reduce error absolute value at maximum speed. The controller should be according to the maximum (or minimum) output, no matter how the tendency it is of deviation change. At the same time in order to prevent the integral saturation, k_p should be larger, k_i should be smaller, and k_d should be zero.

2) When $e \times ec > 0$, error is changing in the direction that error absolute value increases. If the error is big, k_p should be larger, k_d cannot too big, and k_i take a smaller value, in order to quickly reduce the absolute value of error. If error absolute value is small, as long as change the trend of error, which is the change in the direction of the error absolute value decreases.

3) When $e \times ec < 0$ or $e = 0$, the controller can take output unchanged due to the absolute value of error in the direction of the decrease or it has reached the equilibrium state.

4) When $e \times ec = 0, e \neq 0$, the curve of the system parallel to the reference curve or consistent, in order to make the system has good steady-state performance, the value of k_p and k_i should be larger, at the same time, appropriate k_d should be taken to avoid set-point oscillation, and considering the system's anti-jamming ability.

The fuzzy rules are realized through programming statements in the DSP programming environment: IF e is $E(k)$ and ec is $EC(k)$, then K_p is $K_p(k)$ and K_i is $K_i(k)$ and K_d is $K_d(k)$.

3 Experimental program

DS main technical parameters as shown in table 1. The opening speed refers to the average speed in the trip of start just opening points to after the points three-quarters travel. The closing speed refers to the average speed of from just closing points to before the points three-quarters travel. Opening and closing time refers to the time of issue instructions to the end of movement.

Table 1 Main technical parameters

No	project name	Motor
1	opening speed(1)/m/s	1.6±0.5
2	closing speed (2)/m/s	1.3±0.5
3	mechanical life /times	3000
4	contact distance /mm	172±2
5	over travel /mm	58±2
6	actuator travel /deg	80

The following technical scheme was put forward in this paper for meet the main technical index in the operation process of DS, and ensure the stability of the DS contact action: (1) closing process: Improved speed in the early stage and reduces speed in the late stage, ensure that the closing speed can be ensured to fulfill the requirements of technical indicators, and also to reduce collision of moving-contact and the static contact when switch in the late of closing, eliminate the bounce.(2) opening process: in over stroke phase the DS contact at a slower speed, save energy, after the point at a rapid speed, to meet the requirements of opening speed technology.

4 Analysis of experimental results

To verify the validity of the speed control system in this paper, the DS motor operating mechanism and it's control system with DSP as the core was set up. The experimental platform is shown in Fig.7. The switch contact distance is 172+2 mm, over travel is 58+2 mm, and the motor turning angles of 80 °. Experimental environment is capacitance capacity: 198000 uf, capacitor voltage: 350 V.

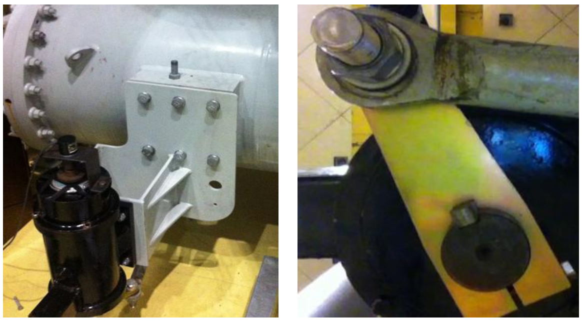

FIGURE 7 DS motor operating mechanism control platform

The experiment which operation process of motor operating mechanism without intelligent speed regulation control and with intelligent control was did in this article; Fig.8 is the movement curves of DS closing.

From Fig.8, the curves 1 is closing movement travel of motor operating mechanism without intelligent control, and the curves 2 is closing movement travel of motor operating mechanism with intelligent control. A is point of opening position, B is point of just closing position, and C is point of closing position. motor turn 80 °.

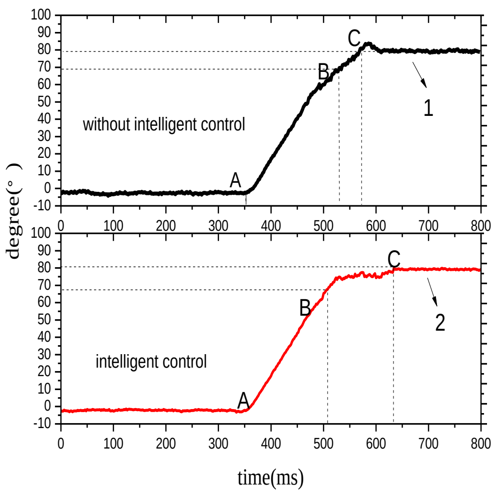

FIGURE 8 Closing movement travel curves of motor operating mechanism

As can be seen from the comparison, DS closing operation time is 230 ms, and closing speed of 1.2 m /s in the curves 1. In the curves 2 DS closing operation time and 270 ms, and closing speed was 1.3 m/s, for the closing speed refers to the average speed of the travel from just closing point to within 3/4 travel before closing.

From the curves 1, after the motor rotate to point C, due to without speed regulation control at the end of movement, the speed of contact is too big lead to the contact collision and 1~2° bounce phenomenon happened. curves 2 is DS contact closing travel curve with intelligent speed regulation control which is obvious the movement speed in the BC contact become slow, to avoid the speed fast of contact movement lead to the collision between dynamic and static contact at the end.

So through the motor operating mechanism with intelligent speed regulation control technology can not only reduce the rate of DS movement after just closing position to reduce the collision force between contacts, to eliminate closing bounce problems, but also meet the requirements of the DS closing speed indicator.

Fig. 9 is DS opening operations contact motion curves. The curve 1 is without speed regulation control technology and curve 2 is with speed regulation control technology. As can be seen from the figure, A is closing point, B is point of just opening position, and C is point of opening position.

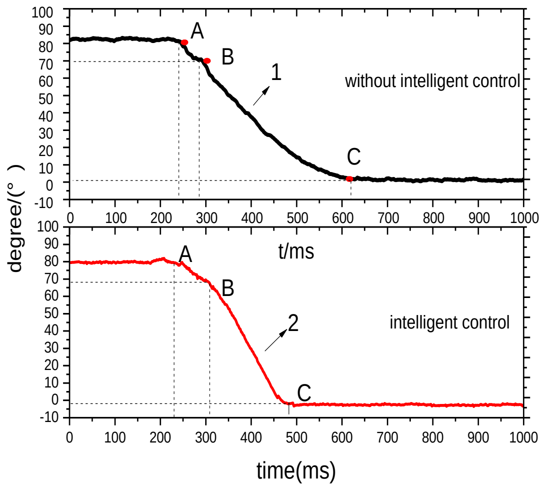

FIGURE 9. Opening movement stroke curves of motor operating mechanism

From the comparison between the curves 1 and curves 2. In the curves 1 DS closing operation time is 380 ms, motor turn 80°, and opening speed 0.5 m/s. Among them A - B is over travel segment of DS, B - C is travel segment of DS. Due to the speed is too fast in over travel segment and in the early of travel used a lot of capacitor energy storage, it will lead to slower speed at the late travel, influence the speed of the whole travel, so that not to reach the DS operation index requirements.

The curves 2 is DS opening travel curve with intelligent speed regulation control. DS opening operation time was 270 ms, motor turn 80°, opening speed 1.1 m/s. The figure shows that in the over travel adjust the PWM duty ratio make contact at low speed running, storing energy, instantaneous release energy in travel, make contact to faster apart, in order to achieve the DS opening technical requirements.

5 Conclusion

In this paper, the control system of the DS motor operating mechanism experiments led to the following conclusions:

1) The intelligent speed regulation control technology can reduce the speed of DS motor operating mechanism after just closing position to decrease the collision force between contacts, and at a certain extent, eliminate closing bounce problem.
2) DS intelligent speed regulation control technology can adjust the opening speed, to make the motor operating mechanism with a faster speed realize opening action. The opening speed was improved 0.6 m/s.
3) The BLDCM operating mechanism can not only provide basic DS drive function, but also implement the intelligent operation of the DS, and provides more application platform of advanced new technology for the high voltage DS operating mechanism.

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