OVERVOLTAGE CONTROL STRATEGY AND TECHNOLOGY OF THE UHV CONTROLLED METAL OXIDE SURGE ARRESTER

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Abstract: A controlled metal oxide surge arrester (CMOA, shortly) was put forward to reduce switching overvoltage in UHV transmission system, based on both the UHV transmission system demand of deeply lowering switching overvoltage and shortcomings of the regular overvoltage limiting measurements. CMOA was made up of a controlled part, MOA1, a fixed part, MOA2 and a switch, K. MOA1 was paralleled with K. On switching overvoltage, K was closed and MOA1 was short circuited to deeply reduce switching overvoltage. On other conditions, K was open, and MOA1 and MOA2 worked together. In order to realize above functions, proper control strategy and advanced technology should be adopted. According to limitation effect of CMOA on switching overvoltage and absorbing energy of MOA2, a control threshold, U_{S0}, and a control rate, α, were confirmed. So a control strategy was set down. Calculation results of CMOA effectiveness on reducing overvoltage indicated that the control strategy was correct. Furthermore, a new control technology based on the break over diode (BOD, shortly) was put forward. Structure and theory of the measuring and control system were given. Simulation experiments were carried out. Results indicated that the measuring and control technology was effective.

1 INTRODUCTION

The UHV AC transmission grid is being built in China to satisfy the requirement of distant, bulky transmission and integrated power system [1]. In UHV AC transmission system, switching impulse discharge voltage shows saturation characteristic. Affect of switching overvoltage level on the difficulty of manufacture and the cost of transmission and transformation equipments becomes even more [1]. It is necessary to deeply reduce the switching overvoltage in order to suitably select lower insulation level for the equipments. The regular measures to reduce switching overvoltage were absolutely realized by protective elements, such as the metal oxide arresters, closing resistors of circuit breakers and shunt reactors [2,3], whose parameters and capability were fixed. Synthetically using regular measures could lower the maximum phase-to-ground switching overvoltage from 1.6 to 1.7 p.u. in UHV transmission system. However, there still exist shortcomings on both economics and operation reliabilities. Therefore, a controlled metal oxide surge arrester (CMOA, shortly) was put forward to reduce switching overvoltage in UHV transmission system [4,5].

2 STRUCTURE AND WORKING PRINCIPLE OF CMOA

2.1 CMOA Structure

CMOA Structure is shown in Figure 1. MOA1 is a controlled part of CMOA and MOA2 is a fixed part. K may be a thyristor switch or spark gap. In this paper, K is a thyristor switch. The working principle of CMOA is that voltage-current characteristic of MOA can be adjusted by controlling the serial number of metal oxide resistor elements in MOA column. K is open on normal condition and MOA1 and MOA2 work together in this case. That implies lower loading voltage rate for CMOA. On transient condition, K is closed to make MOA1 be short-circuited. In this case, residual voltage of CMOA consists only of MOA2, which makes the switching overvoltage greatly be reduced.

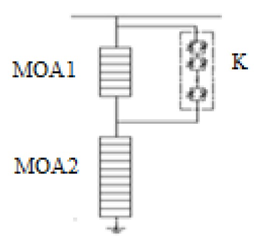
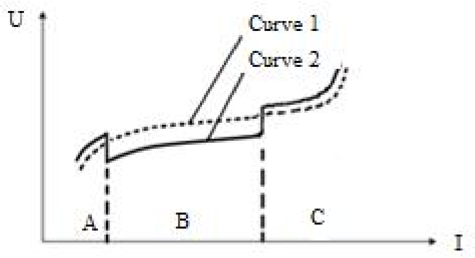


Figure 1: CMOA Structure

2.2 CMOA working principle

2.2.1 Voltage-current characteristic of CMOA

By working principle of CMOA, the voltage-current characteristic of CMOA was drawn as curve 2 shown in figure 2. Curve 1 is the voltage-current characteristic of regular MOA. Rated voltage of CMOA is 890kV, which is more than rated voltage of regular MOA, 828kV. So, when K is open, voltage of CMOA is more than that of MOA. Once K is closed, voltage of CMOA is lower than that of MOA.



A: Power frequency voltage and overvoltage; B: Switching overvoltage; C: Lightning intruding overvoltage

Figure 2: Voltage-current characteristic of CMOA

2.2.2 Theory on power frequency voltage and overvoltage

On power frequency voltage and overvoltage, CMOA works in area A with K being open. Both MOA1 and MOA2 withstand power frequency voltage and overvoltage. The CMOA loading voltage rate can be reduced from 77% to 71% and the operation security can thus be greatly improved.

2.2.3 Theory on switching overvoltage

On switching overvoltage, once K's voltage is higher than its triggered value, K is closed and MOA1 is short-circuited. In this case, CMOA works in area B. The residual voltage of the CMOA consists of MOA2 only, which makes the switching over-voltage reduced to a lower level.

2.2.4 Theory on lightning intruding overvoltage

On lightning intruding overvoltage, CMOA works in area C. MOA1 and MOA2 works together. However, the residual voltage of CMOA is higher than that of MOA. So the lightning overvoltage of equipments will be higher. Such problem can be solved by adjusting number and place of CMOA.

3 CMOA CONTROL STRATEGY

3.1 Control parameters selection

The control parameters of CMOA were shown in Table 1.

Table 1: Control parameters of CMOA

Rated voltage, U_R in kV		890
Continuous operating voltage, U_C in kV		635
Reference voltage, U_{REF}(8mA) in kV	AC	890
	DC	1197
Residual voltage, U_{RES} in kV	1kA	1071
	2kA	1088
	10kA	(1178,1571)
	20kA	(1268,1691)
Discharge capability, I_D in kA	MOA1	≤8
	MOA2	8
Control threshold, U_{S0}		1.3 in p.u., 291.85 in kV
Control rate, α		25%

3.2 Control strategy

On operation, CMOA withstands four voltage and overvoltage, which are power frequency voltage, power frequency overvoltage, switching overvoltage and lightning overvoltage.

On power frequency voltage, power frequency overvoltage less than 1.3p.u. or switching overvoltage less than 1.3p.u., withstand voltage of K is less than 291.85kV. K is open. Both MOA1 and MOA2 withstand voltage.

On switching overvoltage more than 1.3p.u., or short-time power frequency overvoltage more than 1.3p.u. and less than 1.4p.u., withstand voltage of K is more than 291.85kV. K is triggered and closed. MOA1 is short-circuited. Residual voltage of MOA2 is low and can deeply depress switching overvoltage level.

On lightning overvoltage, though withstand voltage of K is more than 291.85kV, wave head time is less than response time of K and K has no time to be closed. Therefore, both MOA1 and MOA2 still withstand voltage together.

3.3 Effectiveness of the control strategy

3.3.1 Calculation conditions

The pilot UHV AC experimental pilot project was used for an example, on which simulation was carried out by ATP/EMTP. The single line diagram of the UHV AC experimental pilot project was shown in figure 3 [7].

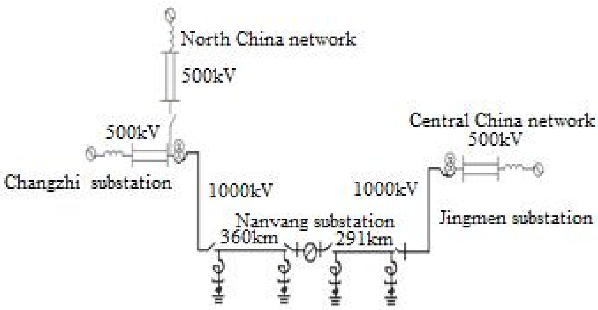


Figure 3: Diagram of the UHV AC experimental pilot project

Effectiveness of CMOA was evaluated on both opening and closing switching overvoltage. Closing overvoltage includes line-energizing overvoltage and single-phase reclosing overvoltage. Opening overvoltage included overvoltage caused by normal opening and load rejection overvoltage caused by single phase grounded fault, as well as transfer overvoltage caused by clearing of a single phase ground fault or three phase grounded fault. There were totally 48 mode combinations considered for system operations and mechanical operations. Overvoltage value was the 2 percent statistical overvoltage for each of the operation modes. The closing resistor, in this case, was 400Ω and the opening resistor was not considered.

3.3.2 Effectiveness on depressing overvoltage by CMOA

For above 48 switching modes, effectiveness on reducing switching overvoltage by CMOA and circuit breakers without closing resistors was evaluated and compared to that of by CMOA and circuit breakers with closing resistors. The max values were checked out and shown in Table 2.

Table 2: Comparison of effectiveness on depressing switching overvoltage by CMOA and by MOA and circuit breakers with closing resistors

Switching overvoltage	measure ments	Overvoltage multiple /p.u. (phase to ground)		
		Line head	Line middle	Line end
Line-energizing overvoltage	MOA and closing resistors	1.52	1.62	1.53
	CMOA	1.44	1.60	1.46
Single-phase reclosing overvoltage	MOA and closing resistors	1.50	1.58	1.51
	CMOA	1.38	1.56	1.39
Opening overvoltage by load dump	MOA and closing resistors	1.50	1.64	1.49
	CMOA	1.36	1.49	1.35
Clearing short-circuit faults transfer overvoltage	MOA and closing resistors	1.58	1.79	1.56
	CMOA	1.47	1.53	1.45

According to Table 2, effectiveness of CMOA was evident, which was better than that of MOA and closing resistors. From the protective ability point of view, closing resistors could only depress the closing overvoltage, and CMOA can depress both closing and opening overvoltage. For example, MOA and closing resistors could depress the transfer overvoltage to 1.79 p.u. caused by clearing three phase ground fault, and CMOA could depress it to 1.53p.u.. Furthermore, for a given system, there would be an optimized closing resistor. Only by CMOA, switching overvoltage could be depressed less than 1.6p.u.. Closing resistors could be cancelled.

4 MEASURING AND CONTROL TECHNOLOGY OF CMOA

4.1 Structure of the measuring and control system

Paper put forward a control method by break over diode (BOD, shortly). The measuring and control system was shown in figure 4, which included a measuring system and a control system. In figure 4, MOA1 is the controlled part of CMOA and MOA2 is the fixed part. K is a thyristor switch. T11, T12, T21, T22, … , Tn1, Tn2 are thyristors which are main components of K and controlled by thyristor electronics board (TE shortly). L1, L2, … , Ln are current limiting reactors of thyristors. MOR1, MOR2, … , MORn are metal oxide resistors to balance voltage of thyristors. The measuring system includes MOA1, MOA2, L and MOR. The control system mainly includes TEs. TE circuit was shown in figure 5. BOD is break over diode which is break down once its voltage exceeds its break down voltage. R1 is current limiting resistance. D1 is diode to limit reverse voltage of thyristor. R2 and C2 make low-pass filter branch circuit. Dz is diode with steady voltage. D2 is diode to prevent thyristor being triggered mistakenly by low disturbing voltage sign.

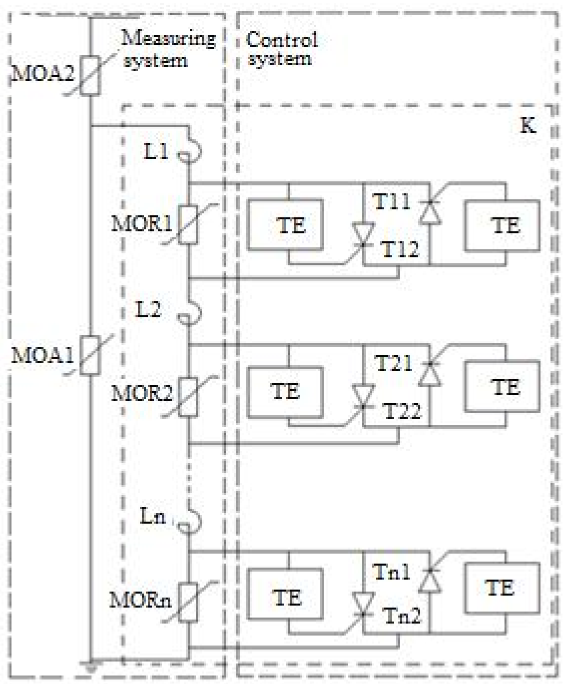


Figure 4: The measuring and control system

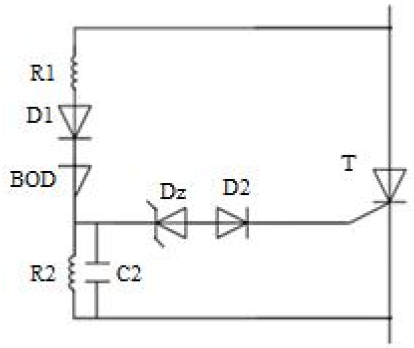


Figure 5: TE circuit

4.2 Working principle of the measuring and control system

4.2.1 The measuring system

Shown as in figure 4 and figure 5, MOA1 and MOA2 can be equal to a primary voltage divider. MOR1, MOR2, …, MORn can be equal to a secondary voltage divider which divides voltage of MOA1 to be n shares. MOR voltage can be put on BOD.

4.2.2 The control system

BOD voltage is compared with its break down voltage threshold, U_{BO}. When BOD voltage is more than U_{BO}, BOD is broken down. Current flows in trigger circuit of BOD. When Dz voltage is up to its steady voltage by R2 and C2 circuit, Dz and D2 are broken down. Current of BOD flows to gate of thyristor and provides a trigger current impulse. On the same time, voltage of thyristor anode has high voltage. So, thyristor can be triggered and closed. Then, K is closed. When thyristor current is less than its holding current, thyristor is open and K is open.

The measuring and control system has such strongpoint as following. (1) Power needed by TE can be supplied by thyristor itself entirely. It needn’t to provide assistant source. (2) TE centralizes the control and trigger functions. Sign conversion and transmission links are saved. So turn-on time of K is shortened consumedly. By test, turn-on time of K, t_{gt}, is only from 1 to 2μs. Entirely satisfy requirements.

4.3 Test verification

In order to testify effectiveness of the measuring and control system, an 110kV CMOA was designed. Test was done in HV testing hall in China electric power research institute (CEPRI shortly). The switching impulse voltage wave was 250/2500μs. CMOA voltage, U1, and K voltage, U2, were shown in figure 6. U10 was operation voltage of CMOA and U20 was operation voltage of K.

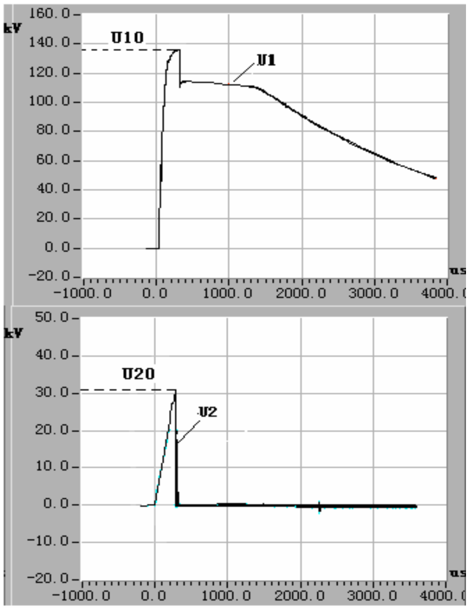


Figure 6: Waves of CMOA and K voltage

As shown in figure 6, U10 was 133.2kV and had an error of 4.1% relative to U_{s0}, 128kV. U20 was 32.3kV and had an error of 0.1% relative to U_{K0} , 32kV. Errors were within accessible scope. Results indicated that CMOA could operate accurately on switching voltage and the measuring and control technology was effective.

5 CONCLUSION

CMOA is made up of a controlled part, MOA1, a fixed part, MOA2 and a switch, K. MOA1 is paralleled with K.

On switching overvoltage more than 1.3p.u., or short-time power frequency overvoltage more than 1.3p.u. and less than 1.4p.u., withstand voltage of K is more than 291.85kV. K is triggered and closed. MOA1 is short-circuited. Residual voltage of MOA2 is low and can deeply depress switching overvoltage level. On other conditions, K was open, and MOA1 and MOA2 worked together.

By the control strategy in this paper, only by CMOA, switching overvoltage could be depressed less than 1.6p.u.. Closing resistors could be cancelled.

Paper put forward a control technology by BOD. The measuring and control system includes a measuring system and a control system. BOD voltage is compared with its break down voltage threshold, U_{BO}. When BOD voltage is more than U_{BO}, BOD is broken down. Thyristor can be triggered and closed. Then, K is closed. When thyristor current is less than its holding current, thyristor is open and K is open.

Simulation test results indicated that CMOA could operate accurately on switching voltage and the measuring and control technology was effective.

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