Study on Voltage Control Method of AC Filter Banks in HVDC Project

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***Abstract*—The single-phase voltage of the AC bus in converter station is applied to control AC filter voltage in Xiluodu HVDC project, the accuracy and reliability are not as good as the three-phase voltage of the multiple-way AC filter banks. This paper presents a new method for controlling AC filter voltage, abnormal bus voltage of AC filter banks are divided into three cases: bus bar not charged, bus voltage over-limit and bus voltage deviation. According to the anomaly type and selection priority of AC filter voltage, a more reasonable AC filter voltage is chose as the output value of AC filter voltage controller. Simulation results show that the application of a new AC filter voltage control method can correctly select the AC filter bus voltage, and avoid the abnormal measurement of AC filter banks voltage which may lead to the unusual switching on/off of AC filters.**

***Index Terms*—HVDC, AC filters voltage control method, abnormality of voltage, bus voltage of AC filter banks, AC filter's switching on/off**

I. Introduction

The AC voltage control is used to keep the AC voltage in the normal operating range and maintain the normal operation of the DC system in HVDC project. It includes the slow adjustment of reactive power control and fast adjustment of over-voltage control. The main object of reactive power control is the AC filters and shunt reactors in converter station, the calculation of reactive power consumption based on the current operating mode and DC voltage and DC current. The reactive power devices are adopted to ensure that reactive power exchange of converter station within the allowable range or AC bus voltage within the safe operating range [1]-[7].

The AC bus is only equipped with single-phase voltage transformer in domestic 500kV HVDC project, DC station control system only collect one phase voltage of AC bus, the phase voltage will be processed into the line voltage which are used to control the reactive power and AC voltage [8]-[10]. In the transient process, there may be deficiency in judging the over-limit of the actual AC filters voltage by single-phase voltage of AC bus, its accuracy is not good as three-phase voltage. Moreover, when one phase voltage of AC bus become abnormal, it may lead to abnormal AC filter's switching on/off. Obviously, there are deficiencies in the accuracy and reliability of the original AC voltage control method which based on single-phase voltage of AC bus.

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II. Problem Description and Pontential Trouble of Xiluodu HVDC

On 28 October 2013, Puqiao HVDC Pole 2 lower-voltage valve group was operating in 1250MW by metallic return mode, and the reactive control was in reactive mode. Switching-on filters were 2A + 1B + 1C. Except for the third AC filter bank (ACF3) in repair state, the other three banks of filters were available. The bus voltage was around 530kV. At 07:08:10, the voltage controller was suddenly activated. As a result, the AC filters were put into operation successively. When all the spinning reserve AC filters were in operation, the maximum value of the bus voltage went up to 572kV. After analysis, it was found that the failure was caused by the transient drop of the fourth AC filter bank (ACF4) bus voltage which is sent to the DC station control system. The voltage validity detection process failed to detect the abnormality of the voltage which triggered the operation of reactive control. The AC filters were switching on successively, and the AC bus voltage was raised.

It is also found that the Xiluodu HVDC transmission system suffer from similar potential trouble. The DC station control (DCC) only collects the A phase voltage of convertor AC #1 and #2 bus, and converting the phase voltage into the line voltage which performs the reactive control. If the phase voltage of the AC bus #1M and #2M is not correct, the AC filters voltage controller may select the abnormal AC voltage which lead to the unusual switching on/off of the AC filters. In order to mitigate the risk of such failure, it is necessary to optimize the DC station control logic of the AC filters voltage in Xiluodu HVDC project.

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III. AC Filters Voltage Control Design Scheme

A. Design Principle and Outline

The basic guideline of voltage control function is as follows:

- There may be deficiency in judging the over-limit of the actual AC filters voltage by single-phase voltage of AC bus. Better accuracy can be achieved based on three-phase voltage.
- The multiple-way voltage of AC filter banks is more reliable than two-way voltage of AC bus.

This paper presents an AC filters voltage control scheme for the Xiluodu HVDC project. The proposed scheme is based on the three-phase AC filter banks voltage rather than the single-phase AC bus voltage. The global logic of the modified AC filters voltage control is shown in Fig. 1.

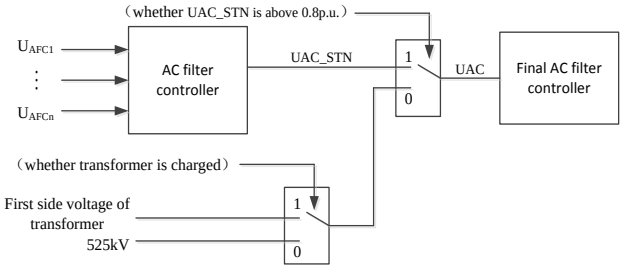

Figure 1. The sketch of the global logic of modified AC filters voltage control

1) Abnormal status of AC filter banks voltage

Abnormal conditions for the bus voltage of AC filter banks can be categorized as: 1) AC filter banks are uncharged; 2) AC filter banks are charged, and the voltages are beyond the limit; 3) AC filter banks are charged, and the voltages are not beyond limit, but different from the voltages of the other AC filter banks in some scope.

2) Uncharged AC filter banks and bus voltage beyond limit

The DC control system judges the charging status of the AC filter banks. If the AC filter banks have been charged, then the voltage over-limitis examined based on the bus voltage of the AC filter banks. The voltage over-limit (including lower limit and upper limit) can be divided into two cases:

- The bus voltage of AC filter bank is beyond the lower limit, UACFn <= 300kV.
- The bus voltage of AC filter bank is beyond the upper limit, UACFn >= 800kV.

The flowchart of judging charge status of AC filter banks and bus voltage over-limit is given in Fig. 2. Suppose the number of AC filter banks is p, ACFn (n=1, ..., p) represents the n-th AC filter bank. If the bank remains uncharged and is beyond the lower limit, the voltage is set to 300kV. If the voltage is beyond the upper limit, 800kV is set. When the voltage is between the upper and lower limit, this AC filter bank voltage is reasonable, the maximum value of the measured three-phase line voltage of this AC filter bank is used as the measurement value for further calculation.

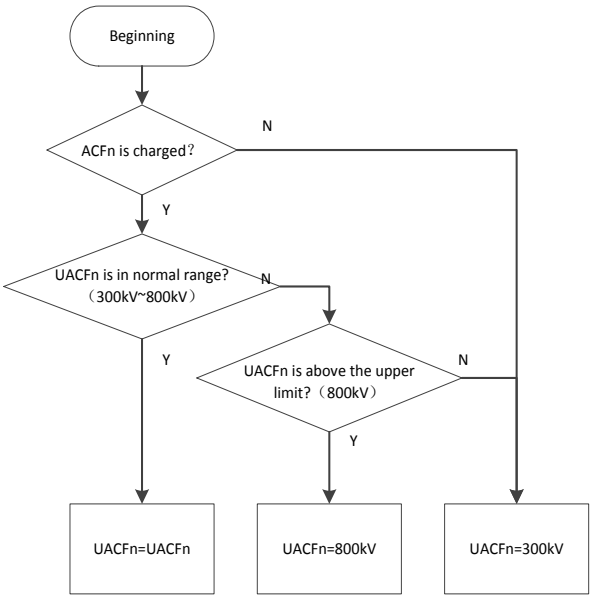

Figure 2. The logic of the filter bank charged and voltage over-limit

3) Deviation of AC filter banks voltage

The "voltage deviation" refers to the situation in which the bank is charged and the measured voltage is in a reasonable range (between 300kV and 800kV), but different from the voltages of the other AC filter banks in some scope.

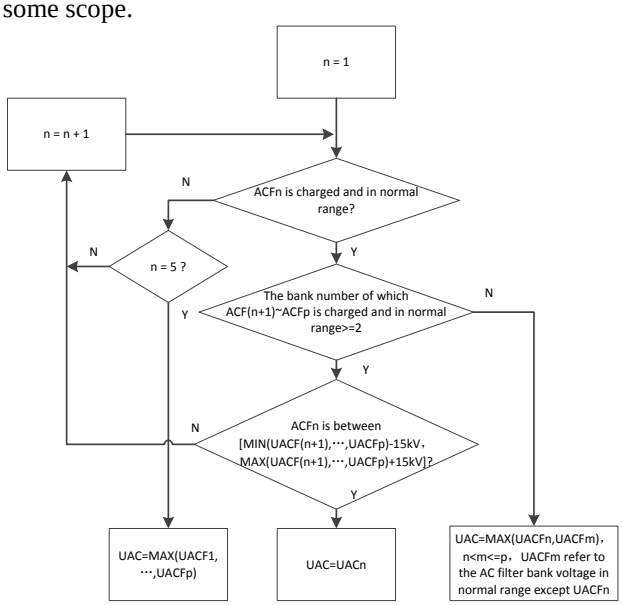

Figure 3. The flowchart of AC filters voltage control

To better illustrate the logic, take examples for the first AC filter bank voltage UACF1, the minimum and maximum values of measured bus voltage of the other AC filter banks are denoted as U_MIN and U_MAX, and are chose to be the reference voltage of UACF1. UACF1 is considered to have voltage deviation when UACF1 <=U_MIN–15kV or UACF1 >= U_MAX+15kV. If ACF1 is uncharged, voltage over-limit or voltage deviation, UACF1 will be eliminated from the voltage selection list. Moreover, it will not be involved in the reference voltage selection of the other AC filter banks. If ACF2 is charged and the voltage is not beyond the limit,

the voltage deviation judgement will be performed for UACF2. For UACF1 has been judged to be in deviation, UACF1 is no longer involved in the reference voltage selection of UACF2. By that analogy, UACF1, UACF2 are not involved in the reference voltage selection of UACF3 when UACF1, UACF2 are unusual. The flowchart of AC filters voltage control is provided in Fig. 3.

The "voltage deviation" probably originates from the abnormality of the measured voltage, or the abnormal reference voltage. If there are more than one filter banks involve the reference voltage selection, the measured voltage is considered to be abnormal. If there is only one filter bank involve the reference voltage selection, we cannot simply judge whether the measured voltage is abnormal or not. In this case, the maximum value of the measured voltage and reference voltage is taken as the output of the AC filters voltage controller. If there is no reference voltage, the measured voltage is instead taken as the output of the AC filters voltage controller.

On extremely case that all AC filter banks voltage are abnormal (uncharged, over-limit, or deviation), the maximum value of the AC filter banks voltage should be selected to be the output of the AC filters voltage controller. When the output of the AC filters voltage controller is lower than 0.8p.u., it is important to examine whether the converter transformer is charged or not. If charged, take the first side voltage of the converter transformer as the final AC filters voltage. If not charged, set the final AC filters voltage as rated voltage.

4) Selection Logic of the AC filters voltage control

Assume there are p AC filter banks in total. UACFn denotes the bus voltage of the nth bank (n=1, ..., p). The modified AC filters voltage control scheme provides the following benefits: 1) Any of the AC filter banks voltage (UACFn) is eliminate from the voltage selection logic when it becomes invalid (uncharged or over-limit). 2) When UACFn exceeds reasonable range, of which the upper limit is MAX(UACF, n+1, …, UACF, p)+15kV, and the lower limit is MIN(UACF, n+1, …, UACF, p)-15kV. 3) All of the AC filter banks voltage are judged valid or not in the sequence of 1, 2, 3, ..., p. 4) If there are only two AC filter banks voltages are valid, take the larger voltage as the output of the AC filters voltage. 5) When all of the AC filter banks voltages become invalid, the final AC filters voltage is set to be the first side voltage of the converter transformer or 800kV.

IV. Simulation Test Scheme and Result

A. Simulation Test Scheme

The proposed AC filters voltage control method need a lot modification of the software programs of the control system. In order to verify the correctness of the method, real time digital simulation are need to verify the following content: 1) The effectiveness and accuracy of the AC filter banks voltage selection logic. 2) The adaptability and effectiveness of the AC filter banks voltage selection under AC voltage disturbance. 3) Whether there is potential risks after the modification of the software programs. The overall scheme of the simulation is shown in Table I.

TABLE I. The Overall Scheme of Simulation Test

Category	Content	Purpose
Program before and after modification	The deviation of AC filter banks voltage is set to 0.83P.U.	Verifying whether the AC filters controller select the right voltage after modification
The condition of AC filter banks	Banks in maintenance	Verifying the correctness and effectiveness of AC filters voltage selection logic
	Voltage deviation	
	Voltage over-limit	
	Combinations of the above condition	
	AC system fault	
Normal function	Power promote and decline, Deblock and block	Verifying whether effect the normal function

Note: Banks in maintenance means the voltage is zero; voltage deviation refers to outside of [Umin-15kV, Umax+15kV]; voltage over-limit refers to outside of [300kV, 800kV].

B. Simulation Results

Take the first or the second group of AC filter banks voltage measurement anomalies as examples to illustrate the effect of the modified logic, other tests' specific results are not listed in this paper.

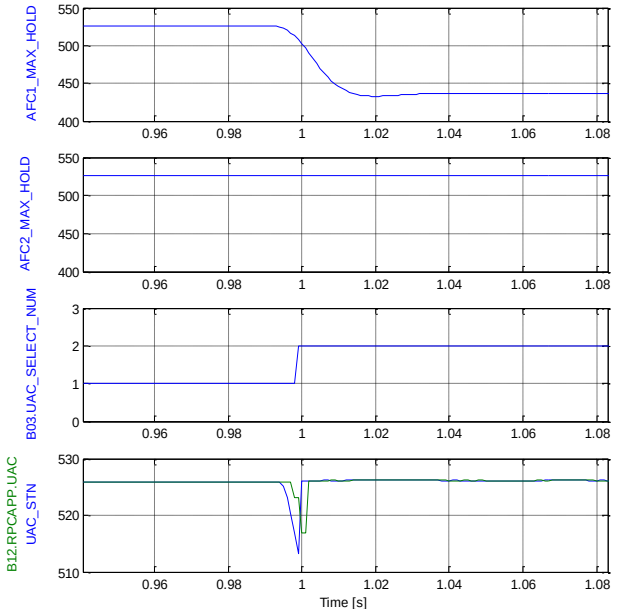

Figure 4. The selection of reference voltage by the deviation of the AC first filter bus voltage

Five banks of AC filter are in operation in rectification station, the first AC filter bank voltage deviate to 0.83pu, the rest banks voltage are normal, 3200MW. The AC filter voltage selection logic takes the second AC filter bank voltage as the reference voltage, as shown in Fig. 4. AFC1_MAX_HOLD is the first AC filter bank voltage, AFC2_MAX_HOLD is the second AC filter bank voltage, B03.UAC_SELECT_NUM is the final selected AC filter bank, UAC_STN is reference voltage selected from UAC1-UAC5, B12RPCAPP.UAC is the final selected AC filters voltage. B03.UAC_SELECT_NUM changes from 1 to 2 which illustrate reference voltage switched from the first AC filter bank to the second AC filter bank.

The final AC filters voltage restored to the normal voltage after the reference voltage selected, which avoid unusual AC filter switching on/off caused by the abnormal voltage of single AC filter bank.

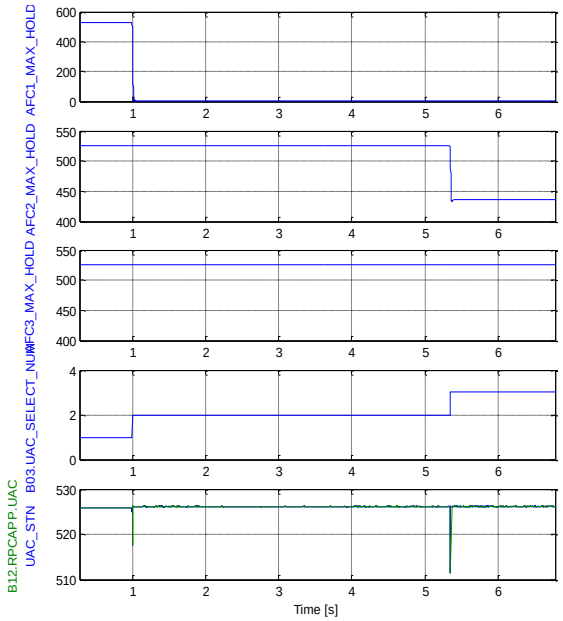

Figure 5. The selection of reference voltage by the deviation of the first and second AC filter banks voltage

As shown in Fig. 5, the 2th, 3th, 4th, 5th banks of AC filter in Xiluodu rectification station operate in the state, the first filter bank operate in maintenance, the voltage of second filter bank deviate to 0.83pu, the rest filter banks are normal, 3200MW. The first AC filter bank is in maintenance, the second AC filter bank voltage would be selected, but there is voltage deviation in the second AC filter bank, at last the third AC filter bank voltage is selected as the reference voltage. AFC3_MAX_HOLD is the third AC filter bank voltage, AC filters voltage eventually stabilize at normal voltage after transient perturbations, which meets the requirements of AC filters voltage control.

The simulation results showed that:

1) Before the logic changes, when the AC filters voltage of the rectification station happens an non-real drop, all AC filters will be put into operation; after modification, all AC filter banks are involved in the AC filters voltage selection logic, the AC filters operates normally under the same conditions.

2) when the AC filter banks is in maintenance, or the voltage is normal, over-limit, deviated, or combination of the above mode, we can choose one of the AC filter banks voltage as the AC filters control voltage in accordance with priority order of 1th, 2th, 3th, 4th, 5th group judged by the following two points: the AC filter banks voltage is valid, the voltage is in the normal range.

3) when only two AC filter banks voltage is valid and do not exceed the range, the larger value of the two voltage is selected as the AC filters control voltage; if all AC filters voltages are abnormal, then first-side voltage of converter transformer or take 800kV is forced to be chose as the AC filters control voltage.

4) After modifying the logic, we don't found any effect on the normal function, such as the deblock/block of the pole, the power promotion and decline, the switching on/off of AC filters, and so on.

V. Conclusion

The single-phase voltage of AC bus is applied in Xiluodu HVDC project to control AC voltage, the accuracy and reliability is not good. In this paper, we use several AC filter banks to select the AC filters voltage. According to filter bank maintenance, voltage deviation, voltage over-limit and the combination of the above cases, and the priority of AC filter banks, the AC filters voltage control logic is redesigned in the control system, which introduces the reference voltage selection logic and anti-error treatment to improve the correctness of the AC filters voltage control method and effectively avoid the bus voltage measurement anomalies lead to unusual AC filter's switching on/off. At present, the proposed method in this paper has been applied in the Xiluodu HVDC project.

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