Facility Requirement Analysis of an UHV Transformer's Short-circuit Test

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Abstract. As the global energy problem becomes more and more severe, the ultra-high voltage (UHV) AC transmission technology will get a large number of applications. The UHV transformer, as one of the important equipments of the transmission system, its quality and reliability is directly related to the safe and stable operation of power system. At present, the normal performance of the UHV transformer is available by test method, except the ability to withstand short circuit need have the aid of calculation and simulation. Based on transformer short-circuit test requirements, the UHV transformer's maximum test ability of Changzhou Inspection & Testing Center for Electrical Equipment and the facility requirement of the commercial UHV transformer's short-circuit test are analyzed respectively in this paper.

Introduction

With the increase of energy demand, the scale of power system is more and more large. Because of large transport capacity, long transmission distance, low line loss, less occupation of land etc, the ultra-high voltage (UHV) AC transmission technology gains more favor in the field of large capacity power transmission over a long distance [1]. In China, there have been two 1000kV AC transmission lines into commercial operation, and there are three similar lines under construction [2, 3]. Predictably, the more severe situation of the global energy problem, the larger number of applications of the UHV AC transmission technology will be got. The UHV transformer, as one of the important equipments of the transmission system, its quality and reliability is directly related to the safe and stable operation of power system [4]. At present, the normal performance of the UHV transformer is available by test method, except the ability to withstand short circuit need have the aid of calculation and simulation [5, 6]. Therefore, Based on transformer short-circuit test requirements, the UHV transformer's maximum test ability of Changzhou Inspection & Testing Center for Electrical Equipment and the facility requirement of the commercial UHV transformer's short-circuit test are analyzed respectively in this paper.

Requirement of the Transformer's Short-circuit Test

For the UHV transformer short-circuit test, the test ability mainly decided by two factors:

One is the total impedance of test loop, namely under the test voltage, whether it has the output current , which is the《IEC 60076.5 Power transformers Part 5: the Ability to withstand short circuit current》required, the other is the working ability of the test equipment itself, to test of the 1000kV transformer, it need to increase the working voltage and the insulation level of the testing transformer.

According to IEC60076.5 rules, the short-circuit test of single-phase transformer satisfies the following equation [7]:

$$Z_s = \frac{U_s^{\ 2}}{S} = \frac{U_s}{I_s} \tag{1}$$

$$Z_t = \frac{U_k \cdot U_r^{\ 2}}{S_r} \tag{2}$$

$$I = \frac{U_r}{Z_s + Z_t} \tag{3}$$

$$I_t = \frac{U_2}{Z_r + Z_t} \tag{4}$$

$$I_t \geq 0.9 \cdot I \tag{5}$$

Where, S is the apparent short circuit capacity of the system, Us is the system nominal voltage, Is is the short circuit current of the system, Zs is the short circuit impedance of the system , Sr is the rated capacity of the test object, Ur is the rated voltage of the test winding, U_k is the short circuit impedance percentage of the test of winding , Zt is the test winding’s short-circuit impedance of the sample transformer, I is the short circuit current value of the test winding under the rated capacity , U_2 is the test voltage which is added to the winding, Zr is the system short-circuit impedance which converts to the side of the U_2 , It is the winding short circuit current value which U_2 under test voltage.

The main technical parameters of 1000kV transformer are as follows: the nominal voltage of high voltage winding is $1050/\sqrt{3}$ kV, the short circuit impedance percentage of high-medium voltage winding is 18%, the 1000kV level system short circuit current is 63kA [8, 9]. Therefore, put the above parameters in formula (1) ~ (3), can get the following equation:

$$Z_s = \frac{1000 \cdot 10^3}{\sqrt{3} \cdot 63 \cdot 10^3} = 9.2\Omega \tag{6}$$

$$Z_t = \frac{0.18 \cdot \left(\frac{1050}{\sqrt{3}} \cdot 10^3\right)^2}{S_r} = \frac{66154}{S_r} \cdot 10^6 \tag{7}$$

$$I = \frac{\frac{1050}{\sqrt{3}} \cdot 10^3}{9.2 + Z_t} = \frac{606236}{9.2 + Z_t} \tag{8}$$

Analysis of the Test Facility Requirement

Capacity of the UHV Transformer

Through research, there are three capacity specifications for the UHV power system, which is shown in the tab. 1 [10]. And it shows that the UHV transformer minimum capacity specification is 400 MVA.

Tab. 1 The UHV transformer specification

No.	Specification	Type	Application Situation
1	1000MVA/1000kV /single-phase	line transformer	used in the UHV AC transmission line
2	1500MVA/1000kV /single-phase	line transformer	successfully developed but not usded in application
3	400MVA/1000kV /single-phase	generator transformer	used in the Huainan Pingwei power plant

Analysis of the CITCEE's Test Ability

As shown in fig. 1, the transformer's short-circuit test system of Changzhou Inspection & Testing Center for Electrical Equipment (CITCEE) include: 2*6500 MVA short-circuit generator and 6*single phase short-circuit transformer.

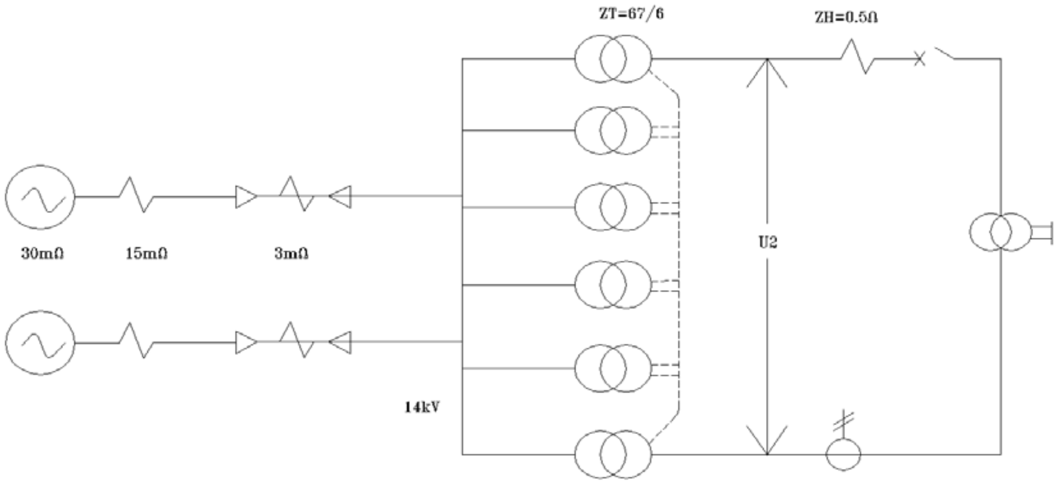

Fig. 1 The schematic diagram of the transformer's short-circuit test system in the CITCEE

The sub transient reactance X_d'' of the generator is 30mΩ, rated voltage is 14kV, the short-circuit transformer, variable ratio is 14kV / 2 * 136kV, the impedance of the side of 14kV is 67mΩ; circuit impedance of high voltage side is 0.5mΩ, which can convert to system impedance about the side of the high voltage:

$$Z_r = \left\{ \frac{\left[(30+15)\cdot 2+3\right]\cdot \frac{1}{2}+\frac{67}{6}}{10^3} \right\} \cdot \left(\frac{U_2}{14}\right)^2 + 0.5\cdot 2 = 0.0577\cdot\left(\frac{U_2}{14}\right)^2 + 1 \qquad (9)$$

Six sets of high voltage short-circuit transformer through vary series and parallel way can get test voltage U_2 is 680kV, 816kV, 952kV and 1088kV.

(1) Put U_2, formula (4), formula (6)-(9) into formula(5),we can get a preliminary scheme of the maximum capacity of the UHV transformer short-circuit test, as is shown in table 2. It shows that the UHV transformer test capacity of CITCEE can only reach 200 MVA, it does not meet the requirements.

Analysis of Minimum Test System Requirement

The calculation in the previous section shows that: the CITCEE is difficult to meet the demands of the commercial UHV transformer's short circuit test, mainly reflected in larger system impedance, the essence of which is test capacity is not enough. Therefore, it is necessary to reduce the high voltage transformer short-circuit impedance, improve its capacity; also need to increase the number of the paralleled short-circuit generator and high voltage short-circuit transformer.

Tab. 2 Short-circuit Test Ability of the CITCEE

No.	Testing voltage （kV）	ratio of test voltage and winding voltage	system impedance （Ω）	The maximum test ability （MVA）
1	680	1.12	137	131
2	816	1.35	197	179
3	952	1.57	268	194
4	1088	1.80	349	200

First of all, to promote high voltage short-circuit transformer parameters: the side of 14kV impedance reduced to 40mΩ,insulation level increase from 330kV to 750kV.

Suppose that number of short-circuit generator is m, number of paralleled high voltage short-circuit transformer is n, internal impedance of the test system can be obtained:

$$Z_r' = \left\{ \frac{\left[(30+15)\cdot 2+3\right]\cdot \frac{1}{m}+\frac{40}{n}}{10^3} \right\} \cdot \left(\frac{U_2}{14}\right)^2 + 0.5\cdot 2 \quad (10)$$

For U_2 is 816kV, can get U_2' is:

$$U_2' = U_2 \cdot \frac{15}{14} \quad (11)$$

Then can get:

$$I_t' = \frac{U_2'}{Z_r' + Z_t} \quad (12)$$

$$I_t' \geq 0.9\cdot I \quad (13)$$

Put formula (6) ~ (8) and formula (10) ~ (12) into formula (13), can get:

$$\frac{93}{m} + \frac{40}{n} \leq \frac{11731}{S_r \cdot 10^{-6}} + 4.045 \quad (14)$$

The physical meaning: when the sample transformer whose capacity is Sr is tested in U_2 voltage, the testing system must satisfy the expression (14) in order to meet the standard requirements.

(1) 400MVA/1000kV Transformer

Put Sr=400MVA into formula (14), we can get m=4，n=6. The minimum system that meets the test requirements is: 4 sets of short-circuit generator and 6 sets of high voltage short-circuit transformer.

(2) 1000MVA/1000kV Transformer

Put Sr=1000MVA into formula (14), we can get m=8，n=12. The minimum system that meets the test requirements is: 8 sets of short-circuit generator and 12 sets of high voltage short-circuit transformer.

(3) 1500MVA/1000kV Transformer

Put Sr=1500MVA into formula (14), we can get m=10，n=16. The minimum system that meets the test requirements is: 10 sets of short-circuit generator and 16 sets of high voltage short-circuit transformer.

On the basis of existing equipments, we need to add new equipments and investments, such as tab. 3. The unit of investment is ten thousand Yuan.

Tab. 3 New equipment requirements for the commercial UHV transformer short-circuit test

No.	list	1000kV					
		400MVA		1000MVA		1500MVA	
		num.	cost	num.	cost	num.	cost
1	6500MVA generator unit	2	24000	6	72000	8	96000
2	circuit breakers, reactors etc. in generator loop	2	10000	6	30000	8	40000
3	transformer(40mΩ, 750kV dielectric level)	0	0	6	16200	10	27000
4	original proposal transformer upgrade costs (Each impedance down to 40mΩ from 67mΩ in 14kV side，dielectric level updated from 330kV to 750kV Level）	6	9000	6	9000	6	9000
5	1100kV SF6 phase-controlled closing switch	1	2000	1	3000	1	3000
6	1100kV loop current transformers, voltage transformers, surge arresters, architecture, etc.	1	1000	1	3000	1	3000
7	2x252kV insulating platform	1	1000	1	1500	1	1500
8	updating measuring equipment	1	500	1	800	1	800
9	sub total	47500		135500		180300	
10	transportation cost (5%)	2375		6775		9015	
11	installation cost (10%)	4750		13550		18030	
Total		64625		155825		207345	

Conclusion

Based on the above analysis, we can get the following conclusion:

(1)Even if we don't consider the insulation level of the equipments, the UHV transformers' short-circuit test capacity of the CITCEE can only reach 200 MVA. It does not meet the practical requirements.

(2)Meeting the requirements of the commercial UHV transformers' short circuit test, the CITCEE need increase a big amount investment to buy the short-circuit generator and the short-circuit transformer.

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