Loss study of HVDC system

LI Zhan-ying[1], REN Zhen[1], CHEN Yong-jin[2]
(1. South China University of Technology, Guangzhou 510641, China;
2. Shaoguan Power Supply Company, Shaoguan 512026, China)

Abstract: It is necessary to quantitatively calculate the losses of HVDC system to reduce its loss and improve its economy. It is difficult to calculate the loss of converter station in HVDC system. According to IEC 61803 of *Determination of power losses in high-voltage direct current (HVDC) converter stations*, the loss calculation models of converter station equipments under different operation conditions are established. The total loss of converter station is the sum of equipment losses, which are calculated separately. Visual Basic 6.0 is used to develop the loss calculation program. The converter station loss calculation for a real HVDC transmission project reveals that, losses of the converter station mainly come from valves and converter transformers, and the total loss of the rectifier station is larger than that of the inversion station.

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0 Introduction

Compared with AC transmission system with same transmission power, the losses of HVDC system are lower and the economic of electric energy transmission is higher[1-4]. The loss calculation of converter station is the difficulty of HVDC system loss calculation. There are some papers[5-8] aimed at the calculation and analysis of the load losses of converter station. No program has been proposed on the loss calculation of converter station or HVDC system.

The transmission power is growing with the increase of HVDC transmission voltage. It is important to study and analyse the losses including HVDC system to improve the economic of HVDC system[9-11].

1 Losses of HVDC system

The losses of the HVDC system are mainly composed of the losses of converter station, HVDC transmission line and electrode line system. Sometimes the line system losses are ignored because of its small quantity.

1.1 Losses of HVDC transmission line

The HVDC transmission line losses are composed of the losses related to voltage and current. The losses related to voltage are mainly composed of corona loss and insulator chain leakage loss. The latter is usually ignored because of its small quantity. The losses related to current are generated by DC current flowing through the line with resistance.

The magnitude of the corona loss is determined not only by the line design parameters such as conductor cross-section, split number and space between conductors, but also by the weather conditions, the surface status of the conductor and the developing stage of the corona, and so on. The corona loss could be calculated with the field test statistical method or the calculation analysis method.

With the measured corona current and DC voltages at both positive and negative poles of DC line, the corona loss could be calculated through the field test statistical method.

$$\Delta P_c = U_{d1} I_1 + U_{d2} I_2 \qquad (1)$$

Where, ΔP_c denotes the corona loss of the bipolar DC transmission line; U_{d1}, U_{d2} are positive and negative DC voltages; I_1, I_2 are positive and negative corona currents.

The resistance losses of DC transmission line could be calculated with

$$\Delta P_d = I_d^2 R_d \qquad (2)$$

Where, ΔP_d is the losses on line resistance caused by DC current; I_d is the DC current; R_d is the resistance of DC line.

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R_d is determined by the operating mode of DC system. The losses caused by the harmonic currents on DC line are usually ignored.

1.2 Losses of DC converter station

The total loss of converter station is the sum of all equipment losses. The converter station equipment includes the vavles, transformer, AC filters, shunt capacitor groups, DC reactor, DC filters, auxiliary equipment RI(Radio Interference)/PLC filters, and so on.

The standard of IEC 61803 *Determination of power losses in high-voltage direct current (HVDC) converter stations* lists the calculation method of each equipment in detail[12].

2 Program of loss calculation of converter station

It's difficult to determine converter station losses by traditional method of direct measurement, since losses are usually less than 1 % of the power transferred, and it leads to inaccuracy of this method[6]. The loss of each equipment is thus calculated, and sumed together to get the total converter station losses[13].

Due to the various loss generation mechanisms, each kind of equipment has a particular loss calculation model, which involves equipment inherent parameters and operational parameters changed with operation conditions, such as direct current I_d, firing angle a and overlap angle u. Some factors should be considered during loss determination. For example, harmonic terms will add noticeable amount to converter transformer and smoothing reactor losses, and the number of shunt compensator and AC filters connected to the system changes with operation conditions[14]. Also, ambient conditions affect losses, so equipment parameters which are measured in factory should be referred to the operational circumstances.

According to the Standard of IEC 61803, loss calculation models for converter station equipment under different operational conditions are established.

Based on basic theory and specific models, loss calculation program for HVDC converter station is developed using Visual Basic programming language. Microsoft's Access is adopted as database for data storage and ADODC method is adopted to realize the connection between database and program.

The structural sketch of a typical HVDC transmission system can be seen in the main window, in which all loss causers at converter station are marked. User can select different equipment, for example, 'AC filters', to check or correct its parameters and calculate its losses. In the main window, user can also accomplish operational parameters maintenance and total loss calculation for 18 operating conditions by clicking corresponding bottoms. All the calculation results can be exported to Excel table for saving or printing.

3 Calculation results and analysis of the loss of a HVDC system

The loss calculation results of the transformers of both converter stations are shown in table 1 and table 2. In all the tables, P_{LossF} means fixed losses; P_{LossV} means variable losses; P_{LossH} means harmonic losses; P_{LossTo} means total losses. There are nine operating conditions are substituted with C_1-C_9, among which C_1 corresponding to the operating condition of bipolar, full voltage, 110 % P_N; C_2 corresponding to bipolar, full voltage, 100 % P_N; C_3 corresponding to bipolar, full voltage, 75 % P_N; C_4 corresponding to bipolar, full voltage, 50 % P_N; C_5 corresponding to bipolar, full voltage, 25 % P_N; C_6 corresponding to bipolar, full voltage, 10 % P_N; C_7 corresponding to single polar, metal return, full voltage; C_8 corresponding to single polar, metal return, 80 % voltage; C_9 correspon-

Tab.1 Loss calculation results of rectifier station transformer

kW

Operating Conditions	P_{LossF}	P_{LossV}	P_{LossH}	P_{LossTo}
C_1	1 560	8 349.13	1 811.11	11 720.24
C_2	1 560	6 905.87	1 713.60	10 179.47
C_3	1 560	3 901.17	1 278.73	6 739.90
C_4	1 560	1 738.82	763.48	4 062.30
C_5	1 560	438.04	314.37	2 312.42
C_6	1 560	146.94	191.29	1 898.23
C_7	780	3 452.94	856.80	5 089.74
C_8	780	3 458.66	938.40	5 177.06
C_9	780	3 469.08	1 163.45	5 412.53

Tab.2 Loss calculation results of inverter station transformer

kW

Operating Conditions	P_{LossF}	P_{LossV}	P_{LossH}	P_{LossTo}
C_1	1 440	6 720.00	1 690.43	9 850.43
C_2	1 440	5 551.82	1 528.45	8 520.27
C_3	1 440	3 133.54	1 108.17	5 681.71
C_4	1 440	1 396.66	690.86	3 527.52
C_5	1 440	351.68	300.31	2 091.99
C_6	1 440	117.84	114.95	1 702.79
C_7	720	2 774.18	733.96	4 228.14
C_8	720	2 781.44	867.89	4 369.33
C_9	720	2 786.65	1 022.26	4 528.90

ding to single polar, metal return, 70 % voltage.

3.1 Loss calculation results and analysis of transformer

The total losses of the converter transformer fall with the decrease of the transmission power under bipolar operation conditions. The total losses of the converter station are nearly the same under the single polar operation conditions. Compared with the rectifier station, the fixed, variable and total losses of inverter station are all smaller.

The fixed losses of converter transformer are its no-load losses, which won't change with the operation parameters. The variable losses, related to transmission power, DC current and harmonic currents, fall with the decrease of DC current obviously.

3.2 Loss calculation results and analysis of the converter station

The loss calculation results of both converter stations are shown in table 3 and table 4. In these tables, $P_{\mathrm{Loss\,T}}$ means losses of the transformers; P_{LossVa} means losses of the valves; P_{LossACF} means losses of the AC fliters; P_{LossDCR} means losses of the DC reactors; P_{LossDCF} means losses of DC filters; P_{LossPLC} means losses of the PLC.

The losses of each equipment in converter station fall with the decrease of the transmission power under bipolar operational conditions. The losses of each equipment in the converter station increase with the decrease of the DC voltage under different single operational conditions. The losses of each equipment in inverter station are lower than those in rectifier station.

The loss proportion of each equipment in converter station under the operational mode condition of bipolar rated transmission power is listed in table 5.

Tab.3 Loss calculation results of rectifier station

kW

Opetating Conditions	P_{LossT}	P_{LossVa}	P_{LossACF}	P_{LossDCR}	P_{LossDCF}	P_{LossPLC}	P_{LossTo}
C_1	11 720.24	7 410.44	884.23	1 525.37	16.64	77.18	22 679.92
C_2	10 179.47	6 872.50	937.62	1 260.13	16.47	63.78	20 389.18
C_3	6 739.90	5 470.08	848.13	709.89	16.21	36.06	14 907.20
C_4	4 062.30	4 039.93	836.00	317.78	16.24	16.12	10 395.24
C_5	2 312.42	2 791.01	537.81	81.79	16.43	4.09	6 862.45
C_6	1 898.23	4 007.11	378.30	31.62	17.56	1.38	7 455.83
C_7	5 089.74	3 435.90	560.99	630.06	8.23	31.89	10 847.93
C_8	5 177.06	3 480.59	598.65	629.38	8.17	31.94	11 016.86
C_9	5 412.53	3 837.81	641.38	629.38	8.09	32.07	11 652.19

Tab.4 Loss calculation results of inverter station

kW

Opetating Conditions	P_{LossT}	P_{LossVa}	P_{LossACF}	P_{LossDCR}	P_{LossDCF}	P_{LossPLC}	P_{LossTo}
C_1	9 850.43	6 453.12	699.20	1 524.51	16.43	77.29	19 621.70
C_2	8 520.27	5 894.15	748.74	1 257.50	16.32	63.84	17 515.98
C_3	5 681.71	4 633.46	771.42	708.80	16.19	36.06	12 889.58
C_4	3 527.52	3 533.48	748.08	318.04	16.30	16.13	9 221.42
C_5	2 091.99	2 637.20	522.52	82.13	16.56	4.09	6 428.38
C_6	1 702.79	2 686.73	256.45	29.64	16.83	1.38	5 770.44
C_7	4 228.14	2 900.61	312.75	628.80	8.17	31.90	9 156.48
C_8	4 369.33	3 216.07	427.83	628.49	8.10	31.99	9 727.81
C_9	4 528.90	3 552.70	544.06	628.67	8.08	32.08	10 340.42

Tab.5 Loss proportion of converter station equipments

%

Equipment	Valve	Transformer	Shunt Capacitor	AC filter	DC reactor	DC filter	PLC filter
Rectifier station	35.44	52.49	0.32	4.83	6.50	0.08	0.33
Inverter station	35.57	51.42	0.42	4.52	7.59	0.10	0.39

It can be seen from table 5 that the losses of converter station are mainly composed of the losses of valve and converter transformer. To decrease the total losses of HVDC system, the losses of valve and converter transformer should be considered first.

4 Conclusions

The difficulty of HVDC transmission system loss calculation falls in the loss calculation of the converter station. To understand the loss proportion of equipment in HVDC converter station and to decrease the losses of HVDC system, a program is proposed to calculate the converter station losses. Based on it, the losses of a real HVDC converter station are calculated and analyzed. The conclusions are summarized as below.

a. The losses of each equipment in converter station are related to the current through it. The equipment losses will increase if the current becomes larger. The total losses of rectifier station are larger than those of inverter station.

b. The losses of converter transformer are composed of fixed losses and variable losses. The variable losses, related to transmission power, DC current and harmonic currents, will fall with the decrease of DC current.

c. The losses of converter station mainly come from valve and converter transformer.

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Biographies:

LI Zhan-ying(1973-),female,born in Jinzhou,China. Ph.D. degree. She mainly focuses her research on HVDC system simulation study(**E-mail**: lzhanying@tom.com).

REN Zhen(1938-),male,born in Yixing,China. Prof. Ph.D. supervisor. He mainly foucses his research on reliabilty study of power system,HVDC system study,and so on.

CHEN Yong-jin(1976-),male,born in Changde,China. Ph.D. degree. He mainly focuses his research on reliability evaluation of HVDC system(**E-mail**:hyperchen@126.com).

直流输电系统网损研究

李战鹰[1],任 震[1],陈永进[2]

(1. 华南理工大学 电力学院,广东 广州 510641;
2. 广东电网公司 韶关供电局,广东 韶关 512026)

摘要: 为进一步降低直流输电系统的网损,提高直流输电系统的经济性,有必要对直流输电系统的网损进行定量计算。直流换流站网损的计算是直流输电系统网损计算的难点。基于IEC 61803标准提出了换流站各电气设备损耗的计算方法,对不同运行方式下、不同负荷水平下的换流站运行损耗进行计算。计算的原理是分别计算换流站内各设备的损耗,然后总加起来得到换流站的总损耗。采用Visual Basic 6.0编制了换流站损耗的计算软件,结合实际的直流输电工程计算其换流站损耗,发现换流站的损耗主要来源于阀和换流变这2个设备,整流站的总损耗大于逆变站的总损耗。

关键词: 高压直流输电系统;换流站;网损计算

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