Research on the Method of Reducing Transformer DCBC Considering Converter Transformer Grouping and Receiving End Power Grid Structure

Chenglian Ma\textsuperscript{1}, Li Sun\textsuperscript{1*}, Shujian Zhao\textsuperscript{2}, Lianguang Liu\textsuperscript{3}

\textsuperscript{1}School of Electrical Engineering, Northeast Electric Power University, Jilin, Jilin 132012, China
\textsuperscript{2}State Grid Jilin Electric Power Co., Ltd., Changchun, Jilin 130001, China
\textsuperscript{3}State Key Laboratory of Alternate Electrical Power System with Renewable Energy Sources (North China Electric Power University), Changping District, Beijing 102206, China

* Correspondence: sunlinedu@163.com

Abstract. Based on the study of the influence of converter marshalling and receiving grid structure on the DC bias current (DCBC), DCBC levels of typical connection structures between converter station and its adjacent substations is analysed in this paper. Then DCBC levels of converter stations and AC substations under different connection modes of substations in AC power network are analysed. The measures to reduce DCBC of converter transformer and AC transformer considering various factors are put forward. A method to reduce DCBC of converter transformer and transformer considering converter transformer grouping and receiving end power grid structure is proposed. The measures of restraining DCBC are analysed from the aspects of operation mode selection, grounding pole location, power grid structure planning and design. Suggestions are put forward for the treatment of DCBC in the planning and design stage.

1. Introduction
The monopole earth operation mode will be used in the initial stage of HVDC project completion and operation mode conversion stage. Under this mode of operation, the DC grounding current through the DC grounding electrode reaches thousands of amperes. A series of hazards will be generated by the large DC grounding current for a long time at the ground electrode site [1-2].

In traditional method, after the DC project is put into operation, DCBC level of the transformer near the grounding electrode is evaluated by measuring DCBC, and then the treatment scheme of the DCBC is put forward. However, in the planning and designing of the transmission receiving end power grid, if the factors affecting DCBC are fully considered and the power grid structure planning and operation mode selection are reasonably carried out, DCBC level can be controlled within a certain range in the planning and designing stage. As for converter station, due to near the grounding electrode, small grounding resistance, small parallel resistance of converter transformers, large number of feeders and high voltage level of feeders, DCBC in the converter station and through the single-phase converter transformer are larger. Moreover, because the converter transformer adopts single-phase and double-winding structure, its excitation current is small and its DCBC tolerance is poor.
Therefore, how to reduce the DCBC of converter transformer has become one of the urgent problems to be solved in the safe operation of the converter station [3-4]. This paper takes into account converter transformer grouping and receiving end power grid structure and presents a method to reduce DCBC of converter transformer and AC transformer. From the operation mode selection, grounding electrode location, power grid structure planning and design, the measures of restraining DCBC are analysed in many aspects. Suggestions are put forward for the treatment of magnetic DCBC in the planning and design stage.

2. Actual problem analysis
In the calculation of DCBC of Xizhe DC receiving end power grid, DCBC level of Jinhua converter station of receiving end power grid and 500 kV transmission line connected with it are higher. Among them, DCBC value of Jinhua converter station is as high as -171.74A. And values of transmission lines from Jinhua converter station to Shuanglong, Danxi and Wanxiang are 119.44A, 18.38A and 33.92A, respectively. A large number of DCBC passing through converter transformer causes a series of hazards such as transformer DCBC, increasing noise, vibration intensification, and higher harmonic component.

For DCBC of converter transformer, this paper presents a method to reduce DCBC by selecting reasonable operation mode and grounding electrode location. In this paper, the measure to reduce the DCBC of AC transformer is proposed in view of the problem of DCBC of the AC transformer in the receiving end power grid. The results show that the main influencing factors of DCBC in receiving end power grid are the distance between substation and grounding electrode, voltage level, line length and number of loops. Voltage level, line length and circuit number are mainly determined by transformer capacity, inter-station transmission capacity, transmission economy and other factors. It is unreasonable to change voltage level, line length and circuit number solely to reduce bias current.

3. The method of reducing DCBC of converter transformer

3.1. The geographic connection of converter stations and their connected substations in engineering examples
HVDC receiving-end power grid of HVDC has been forming a certain scale before the construction of HVDC. In the process of HVDC transmission, the transmission capacity of HVDC is accepted by expanding the existing substation network and transmission line. Because the location of HVDC grounding electrode is directly related to DCBC level and operation safety of the substation nearby, how to choose the grounding electrode site correctly is a major problem in the HVDC transmission process. The distance between Xizhe and Hazheng receiving end converter station and grounding electrode is 23.5 km and 34.9 km, respectively. The short distance between the converter station and the grounding electrode, and the large difference between the converter station and the connected substation result in the high DCBC of the converter station and the AC substation. Figure 1 is the geographic wiring diagram of Xizhe and Hazheng converter station and their connected substations. The typical structure is shown in figure 2. Among them, α, β, and γ are the angles between the corresponding contact lines, and α < β < γ [5].

![Figure 1. The converter engineering and connected substation geographical wiring diagram.](image-url)
3.2. Typical geographic connection of converter stations and their connected substations
In order to analyse the selection of the grounding electrode site under the typical wiring structure shown in Figure 2, to reduce DCBC commutation, as shown in Figure 2, the vertical bisector of each tie line is made. The intersection point of the two vertical bisection lines is equal to that of the corresponding two substations and the converter stations, and each intersection point is selected as the proposed pole location and the label respectively. Table 1 gives the distance between the converter stations and substations from the three different polar sites, and gives the difference between the distance from the special station (the distance from the grounding electrode) and the difference value between the distance from grounding electrode and the distance between grounding electrode and the converter station.

Table 1. Distance between converter station and substation from grounding electrode at different sites.

| Converter station | Station 1 | Station 2 | Station 3 | Distance difference $\Delta L$ |
|-------------------|-----------|-----------|-----------|-----------------------------|
| Site1             | $L_1$     | $L_1$     | $L_1$     | $L_4$                      |
| Site2             | $L_2$     | $L_5$     | $L_2$     | $L_2$                      |
| Site3             | $L_3$     | $L_3$     | $L_6$     | $L_3$                      |

3.3. Location of grounding electrode in order to reduce the analysis of changing and changing magnetic current method
Due to $\alpha < \beta < \gamma$, according to the graphical structure diagram and the mathematical knowledge, it can be obtained as $L_1 < L_2 < L_3$. And $\Delta L = L_4 - L_1 = L_5 - L_2 = L_6 - L_3$, when the electrode location is site 1, the special station is nearest to the grounding pole, and when the electrode location is site 3, the special station is farthest from the grounding pole. In order to illustrate the variation of earth potential difference between substations at the beginning and the end of the line with the distance under the same distance span of the radiation direction of the ground electrode. The variation of earth potential in the 5–50 km range of the Jinsi grounding electrode is given in figure 3.

Figure 3. The earth potential 5–50km away from Jinsi.
4. Method of reducing DCBC of AC transformer

4.1. Influence factors of magnetic bias current in end grid
Aiming at the DCBC problem of converter transformer, this paper proposes a method to reduce DCBC by reasonable operation mode selection and grounding electrode location selection. In this part, the measures to reduce DCBC of AC transformer in the receiving power grid will be put forward in order to solve the problem of bias current of AC transformer in the receiving end power grid [6-13].

4.2. Analysis of magnetic bias current of AC transformer substation
In order to study the influence of the distribution mode of the AC substation on the DCBC of the hub station, it is assumed that the hub substation is connected with eight substations, and only DCBC level of the hub substation is analysed. As shown in Figure 4, the center of the grounding electrode is used as the equipotential line of the earth potential near the grounding electrode to keep the position of the hub substation unchanged and to change the relative position of eight substations with the grounding electrode. Five specific connection modes are illustrated. The distribution of DCBC under different connection modes is analysed, and the values of DCBC under different connection modes are listed as shown in Table 2. In \((n = 1, 2, \ldots, 8)\) is the absolute value of DCBC in substations.

![Figure 4. Different connection modes of relative grounding electrodes and hub stations in multiple substations.](image)

![Table 2. DCBC Level of Hub Substation under Different Connection Modes.](image)

| Connection mode | Number of substations farther from the grounding electrode than the hub station | Number of substations closer to grounding electrode than hub station | Grounding bias current of hub substation |
|-----------------|-------------------------------------------------|-------------------------------------------------|---------------------------------------------|
| a               | 8                                               | 0                                               | \(-\sum_{n=1}^{8} I_n\)                     |
| b               | 6                                               | 2                                               | \(-\sum_{n=1}^{6} I_n + \sum_{n=7}^{8} I_n\) |
| c               | 4                                               | 4                                               | \(-\sum_{n=1}^{4} I_n + \sum_{n=5}^{8} I_n\) |
| d               | 2                                               | 6                                               | \(-\sum_{n=1}^{2} I_n + \sum_{n=3}^{8} I_n\) |
| e               | 0                                               | 8                                               | \(\sum_{n=1}^{8} I_n\)                     |
5. Conclusion
1) When choosing the location of grounding electrode in DC project, the electrode location should be as far as possible from the converter station and AC substation in order to reduce the earth potential of each grounding point in the receiving end power grid, the earth potential difference between connected substations, and the bias current of transmission line. Then reduce the over-conversion current and DCBC of AC the converter station and substations.
2) In the actual network, it is difficult to locate most substations and hub substations on the equipotential line by grounding electrode location. But in the process of grounding electrode location and power grid structure planning and designing, it is avoided to make all substations closer or farther from the grounding electrode than the hub station. And to control the number of substations closer to the grounding electrode than the hub station, so that the number of substations distributed in the hub substation is not too large. DCBC of the connection lines on both sides of the bit line is partly offset by the bus of the hub station, so as to reduce DCBC of the AC transformer in the hub station.

6. References
[1] Harrison C W, Anderson P I 2016 Characterization of Grain-Oriented Electrical Steels Under High DC Biased Conditions (IEEE Transactions on Magnetics). vol 52 chapter 5 pp 1-4
[2] Kazerooni M, Zhu H, Overbye T J 2017 Improved Modelling of Geomagnetically Induced Currents Utilizing Derivation Techniques for Substation Grounding Resistance (IEEE Transactions on Power Delivery). vol 32 chapter 5 pp 2320-2328
[3] Chenglian Ma, Liu L, Wang L, Bo L, Jiang K 2017 The ANSYS Simulation of HVDC Grounding Electrode Potential Distribution (Power System & Clean Energy). vol 33 chapter 4 pp 19-26 (in Chinese)
[4] Yang Mao, Yang Chunlin 2018 Research of Wind Power Prediction Considering Wind Direction (Journal of Northeast Electric Power University). vol 38 chapter 5 pp 9-15 (in Chinese)
[5] Mousavi S A, Bonmann D 2017 Analysis of asymmetric magnetization current and reactive power demand of power transformers due to GIC (Procedia Engineering). vol 202 pp 264-272
[6] LU Zhiwei, ZHANG Hang, AO Ming, YU Hai and LI Yanfei 2016 Research of Thermal Time Constant and Steady Criterion used in the Power Cables Ampacity Test (Journal of Northeast Dianli University). vol 36 chapter 5 pp 25-31 (in Chinese)
[7] Liu Qi, Lu Zhiwei, Shi Liu, Jiang Longjie, Kong Shen 2018 Optimization of Calculation of Impulse Grounding Resistance of Tower Considering Spark Effect (Journal of Northeast Electrical Power University). vol 38 chapter 4 pp 8-13 (in Chinese)
[8] Zhu He, Hu Yiyang 2017 Simulation and Research on Steady State Electromagnetic Interference on Pipelines Caused by High Voltage Transmission Lines (Journal of Northeast Electrical Power University). vol 37 chapter 3 pp 83-89 (in Chinese)
[9] Zhu He, Li Bingkun 2017 Huainan-Shanghai UHV Electric Imbalance and Transposition Mode Simulation (Journal of Northeast Electrical Power University). vol 37 chapter 4 pp 45-51 (in Chinese)
[10] Zhu He, Liu Hao, Li Benzeng 2017 Study on the Influence of Air Humidity on the Ion Current Field of UHVDC Transmission Line (Journal of Northeast Electric Power University). vol 37 chapter 6 pp 86-92 (in Chinese)
[11] Fu Gui, Wang Zihang, Li Jiang, Cui Weifeng 2018 Additional Power Change Control for Modular Multilevel Converter Based on Flexible HVDC Systems (Journal of Northeast Electrical Power University). vol 38 chapter 5 pp 16-22 (in Chinese)
[12] Lin Guoxin 2017 Study and Comparison on Construction Plan of The Cross-sea HV Transmission Line to Connect The Isolated Islands and The Mainland (Journal of Northeast Electrical Power University). vol 37 chapter 4 pp 86-93 (in Chinese)
[13] WU Wenke, LU Zhiwei, ZHANG Hang, AO Ming and LIU Tongtong 2016 Research on Dynamic Capacity Increase and Double-Circuit Capacity Increase Strategy for Buried Power Cable (Journal of Northeast Dianli University). vol 36 chapter 5 pp 7-12 (in Chinese)
Appendices
This work is supported by National Key Research and Development Program of China (2016YFC0800100); and Supported by National Natural Science Foundation of China (51677068, 51577060); and Shandong Electric Power Engineering Consulting Institute CO., Ltd., (37-K2017-021).