Design of Grounding System of Fuzhou Ultra-High Voltage Substation

Zhihe Lin
Fujian Power Grid Cooperation, Fuzhou
e-mail: lin-zhihe@139.com

Weihua Ma
State Grid Cooperation of China, Beijing
e-mail: sgccmwh@163.com

Hanbo Liu, Bin Zhang
Department of Electrical Engineering, Tsinghua University, Beijing
e-mail: liuhb10@qq.com, zbxjtu@126.com

Jiayong Zou
Southwest Electric Power Design Institute
Chengdu, Sichuan
e-mail: zou_jiayong@qq.com

Abstract—The grounding system of the ultra-high voltage substation is of great significance in safe operation of the substation. The grounding resistance value of the grounding system of the ultra-high voltage substation in the basic plan is far more than the allowable value. The paper analyzes the common resistance reduction measures, considers the safety and the practicability according to the actual situations of the substation and puts forwards the following several possible resistance reduction measures of exterior-leading grounding, oblique grounding and vertical grounding, deep well grounding, blasting grounding and so on. The analysis result shows that the grounding resistance value can be reduced to the allowable range.

Keywords- Ultra-high voltage substation; grounding system; exterior-leading grounding; vertical grounding; deep well grounding; blasting grounding

I. INTRODUCTION

Before the design of the grounding system of Fuzhou ultra-high voltage substation, mainly consider the following three principles:

1) Safety: the grounding resistance value is the important indicator of measuring the validity and the safety of the grounding system and identifying whether the substation grounding system meets the regulations and the requirements or not.

2) Practicability: due to the influence of surrounding terrain, geology, land acquisition, underground water source distribution and other factors, comprehensively consider the practicability of the plan and formulate the practical and feasible grounding system design plan and the resistance reduction and implementation plan.

3) Economy: on the premise of meeting the safety and the practicability, reduce the engineering cost to the great extend. Due to the characteristics of Fuzhou substation self, different implementation schemes may bring along different engineering cost.

The paper mainly considers the design process of the substation grounding system from two aspects of practicability and safety.

II. BASIC PLAN OF SUBSTATION GROUNDING SYSTEM

The land acquisition situation of Fuzhou substation is shown in Fig .1. The land acquisition range forms the main body of the substation grounding grid.

Through calculation, after the completion of horizontal grid pavement, the grounding resistance is about 6-7 Ω roughly and is far more than the allowable value.

III. COMMON RESISTANCE REDUCTION MEASURES

There are many research on grounding in literature [1-16].

1) Enlarging the area of the substation grounding grid:

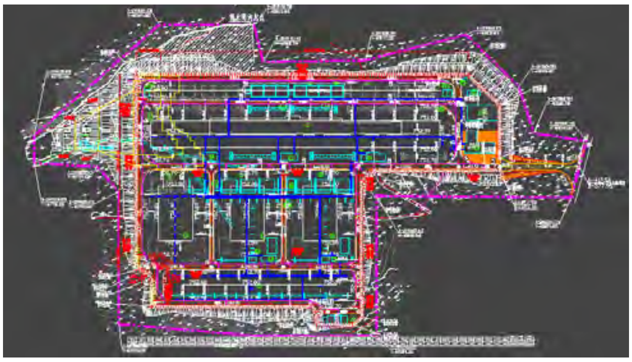

Figure 1. Land Acquisition Situation of Fuzhou Substation.

The grounding resistance of the substation grounding grid is in inverse proportion to the square root of the grounding grid area approximately, and the greater the area is, the lower the grounding resistance is. The effective method of reducing the grounding resistance of the substation grounding grid is to increase the area of the substation grounding grid.

2) Exterior-leading grounding: Exterior-leading grounding is a method of connecting the main substation grounding grid and the auxiliary grounding grid paved in a certain low-soil resistivity area outside the main grounding grid area so as to achieve the purpose of reducing the grounding resistance of the whole grounding system.

3) Natural grounding: Natural grounding involves in reinforced concrete steel skeleton of the surrounding building, hydropower station water inlet trash rack, gate, water diversion pipe and soon. The natural grounding electrodes are fully utilized to reduce the grounding resistance, so that not only is the grounding resistance easy to reduce technically, but also the technical and economic benefits are better.

4) Long vertical grounding, blasting grounding and deep well grounding: If the lower low-resistivity layer exists in the soil where the grounding system is arranged, the long vertical grounding, the blasting grounding or the deep well grounding can be adopted. The low-resistivity materials are generally used in the deep well grounding to obtain lower grounding resistance. As backfill materials can absorb the moisture from the ambient environment, the grounding well can not be dry without any maintenance. A huge low-resistivity area can also be formed by a deep-hole blasting crack-pressure irrigation resistance reduction method so as to achieve the purpose of reducing the resistance.

IV. ANALYSIS ON RESISTANCE REDUCTION MEASURES POSSIBLE TO IMPLEMENT IN FUZHOU SUBSTATION

A. Exterior-leading grounding

On the premise that there is a big enough low-resistivity area for exterior leading, a feasible method of reducing the grounding resistance of the substation grounding grid is to increase the area of the substation grounding grid.

In order to conveniently illustrate, five areas, i.e. areas A, B, C, D and E are marked on the periphery of the substation, as shown in Fig .2.

The area A is dry land on which there is a small hillside or below the hillside and is positioned in the north. It is narrower compared with the station and is not

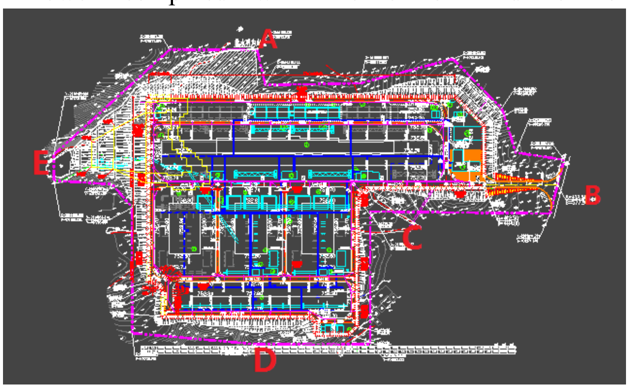

Figure 2. Areas on the Periphery of Substation

expropriated, and there is no evidence to show that a low-resistivity area may exist here.

The area B is adjacent to the county road 115, and the other side of the county road, which is far away from one side of the substation, is a forest area and a residential area.

The area C is adjacent to the site, so the connection is more convenient if the grounding grid can be expanded in this area. But, it is a forest area in which residents live.

The area D still is a hillside below which there is a small quantity of paddy fields. The paddy fields and the hillside are not expropriated.

Through comparison, the area E is easy for exterior leading, which is positioned in the gully of two hillsides, two water ponds in the gully have been dredged and filled, and the water in the gully finally flows into the mountain stream outside 300 meters. A part of area on the periphery of the gully has been expropriated; and meanwhile, the three sides of the gully are hillsides, so the transportation is not convenient, and few people live. Therefore, the area E belongs to the grey area.

But, it is necessary to point out that the stream in the area is narrow and shallow and has less water yield, and there are many rocks at the bottom of the stream, so that the area E is not suitable for large-scale pavement of the grounding grid. But, according to the design of the substation, there is a drainage ditch directly connected with the stream in the gully, so the additional cost is low if the exterior leading conductor is paved in the sludge nearby the steam along with the drainage ditch.

In addition, the access road and its two sides have been expropriated. Due to high-quality surface soil, we can firstly consider the pavement of the horizontal grid and then consider whether the deep well grounding electrodes are increased during construction or not.

Because of the above factors, above the basic grounding grid, increase and extend the exterior-leading conductors at the gully into the stream, as shown in Fig .3.

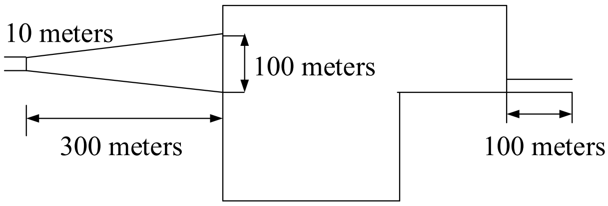

Figure 3. Schematic Diagram of Conductors Paved in the Gully

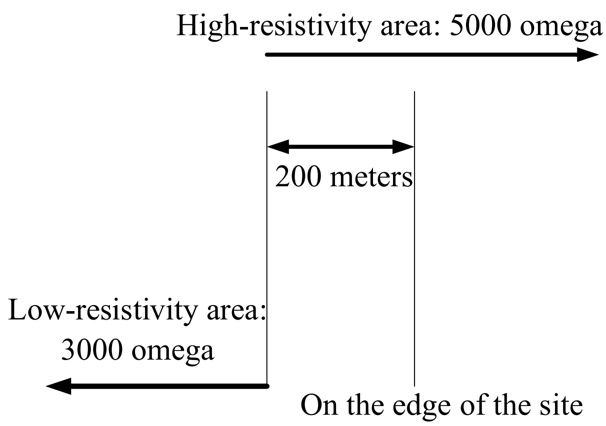

Figure 4. Model of Soil at the Stream

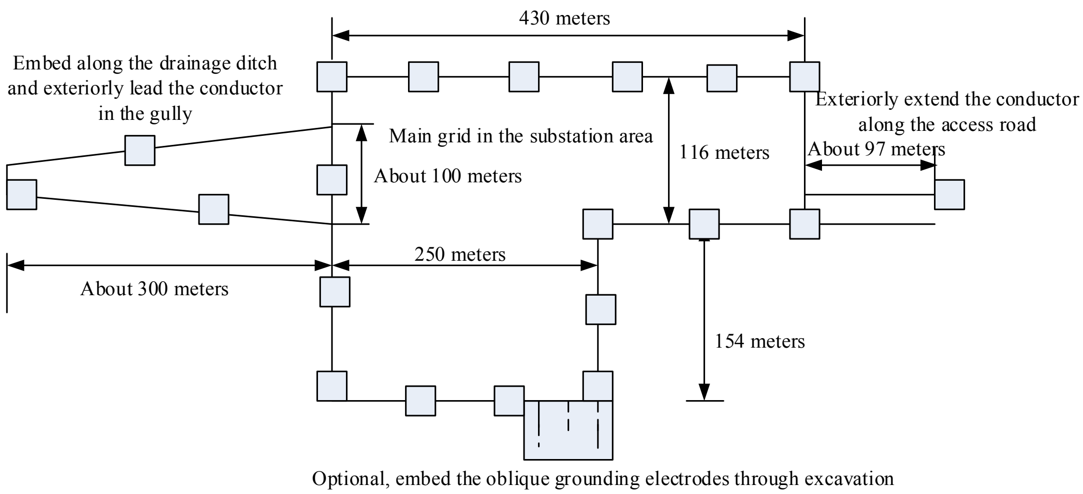

Figure 5. Grounding Electrodes of 20 Deep Wells

Under the situation that the resistivity difference of soil is not considered, and particularly, the resistivity difference of soil nearby the stream is not considered, the grounding resistance of the whole grounding grid is about 6 Ω through calculation.

Under the situation of considering that the resistivity of soil at the stream is lower than that in the substation, the resistivity of soil in the substation shall be equivalently treated. If the resistivity of soil at the stream is 3000 omega, on the premise that the grounding resistance of the horizontal grid in the substation is 7 Ω and is not changed, the soil resistivity is equivalent to be 5000 omega, and the grounding resistance is 5.8 Ω.

We estimate that after the above exterior leading is well done, the grounding resistance is about 5.6-6.0Ω and is about 85 percent of that of the horizontal grid.

B. *Oblique grounding*

Although the oblique grounding has the double effects on vertical grounding and grid expansion, it is not recommended to be used in Fuzhou ultra-high substation as the soil covered on the local surface is thin, there are many rocks under the ground, and the rock thickness exceeds 1 meter to result in that the oblique grounding electrodes can be embedded into the ground only through excavation.

But, in the backup plan, the oblique grounding electrodes can be considered to be embedded into the paddy field in the southwest direction of the site through excavation. The soil on the surface of the paddy field contains more moisture to play a certain role in reducing the resistance.

C. *Vertical grounding*

We consider that the vertical electrodes are increased based on proper exterior leading of the horizontal grid. Due to larger grounding grid, the vertical electrodes can not be shielded as long as they are long enough. 20 100-m long vertical electrodes are increased. After three different soil models are considered, the obtained grounding resistance is shown in Table I.

TABLE I
GROUNDING RESISTANCE VALUES OF VERTICAL ELECTRODES UNDER DIFFERENT SOIL MODELS

Soil Models	Grounding resistance (Ω) after exterior leading	Increased vertical electrodes (Ω)
Model 1	6.1	5.6
Model 2	5.6	5.3
Model 3	5.8	5.3

D. *Deep well grounding*

The reason for why the underground water affects the soil resistivity is that the underground water can be used for filling avoids in the soil, increasing the diffusion area of the soil and shortening the diffusion channel of the soil. The deep well grounding technology means the grounding electrodes made by utilizing the principle of water accumulation in the well.

We consider that the deep well grounding electrodes are increased on the basis of proper exterior leading of the horizontal grid. The deep well is considered, as shown in Fig .5.

After three different deep wells are considered, the obtained grounding resistance is shown in Table II.

TABLE II
GROUNDING RESISTANCE VALUES OF WELLS WITH DIFFERENT DEPTH

Deep Wells	Grounding Resistance after exterior leading (Ω)	Grounding Resistance after the wells are deepened (Ω)	Proportion (Well deepening / exterior leading)
100	5.6	3.63	0.65
80	5.6	4.10	0.73
60	5.6	4.77	0.85

E. *Blasting grounding*

The blasting grounding technology means that the drilling machine is adopted to vertically drill the hole with a certain diameter and a certain depth in the ground, the grounding electrodes are inserted into the hole, then explosives are placed along the hole depth at certain spaces for blasting to crack and loosen the rocks, and

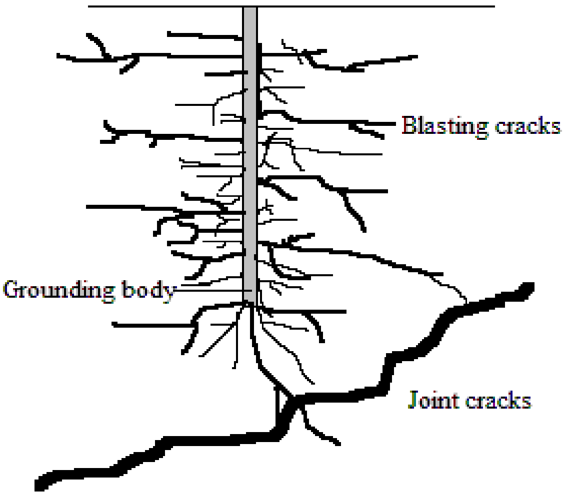

Figure 6. The single vertical grounding conductor adopts the blasting grounding technology and fills the area in which the low-resistivity materials are pressed.

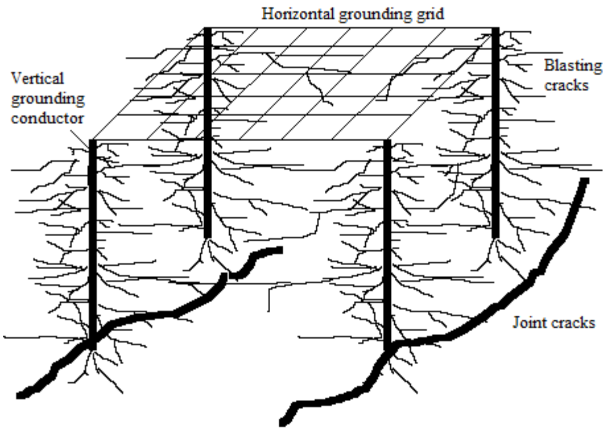

Figure 7. Three-dimensional Mesh-shaped Structure Grounding Conductor after the Substation Grounding Grid adopts the Blasting Grounding Technology.

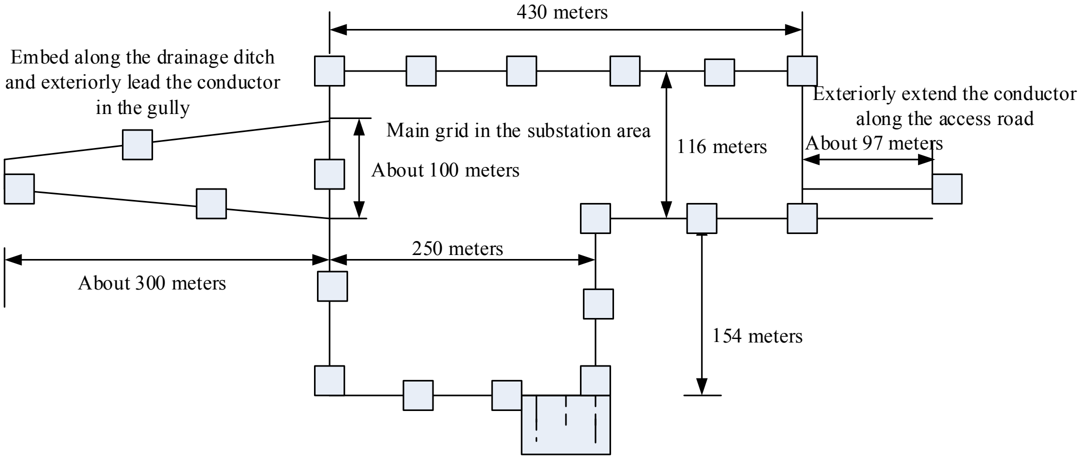

Figure 8. Schematic Layout of Blasting Grounding Electrodes

finally, the pasty low-resistivity materials are pressed by the press machine into the deep hole and the cracks generated by blasting so as to achieve the purposes of communicating the inside of the rocks within a huge range through the pasty low-resistivity materials and enhancing the contact of the grounding electrodes with the soil (rocks), thereby greatly reducing the grounding resistance. The vertical hole has a depth of 30-120 m generally.

We consider that 20 80-100-m deep blasting grounding electrodes are increased in positions shown in Fig .8 and can meet the requirement for the grounding resistance limit value through calculation.

V. CONCLUSIONS

After the horizontal grid of Fuzhou substation is paved, the grounding resistance is about 6-7 Ω and is far more than the allowable value. Through considering the common resistance reduction measures, the several plans possible to implement are put forward.

1) After exterior-leading grounding is adopted in the area E nearby the substation, the grounding resistance is about 5.6-6.0 Ω and is about 85 percent of that of the horizontal grid.

2) In the southwest direction of the substation area, the oblique grounding electrodes are considered to be embedded into the paddy field through excavation.

3) With the adoption of 20 100-m long vertical grounding electrodes, the grounding resistance can be reduced to 5.3-5.6 Ω.

4) With the adoption of the deep well grounding electrodes, the resistance can be effectively reduced; with the adoption of 20 100-m deep grounding wells, the grounding resistance can be reduced to 3.6 Ω.

5) With the adoption of 80-100-m deep blasting grounding electrodes, the requirement for the grounding resistance limit value can be met.

REFERENCES

[1] Li Zhongxin, Yuan Jiansheng, Zhang Liping. Numerical analysis of substation grounding systems [J]. Proceedings of the CSEE, 1999, 19(5): 75-79(in Chinese).

[2] Zhang Bo, Cui Xiang, Zhao Zhibin, et al. Analysis of grounding grids at large scale substations in frequency domain [J]. Proceedings of the CSEE, 2002, 22(9): 59-63(in Chinese).
[3] He Jinliang, Kang Peng, Zeng Rong, et al. Grounding system design of Wudaoliang and Tuotuohe substations for 110kV power transmission engineering of Qinghai-Tibet railway[J]. Power System Technology, 2006, 30(1): 55-59(in Chinese).
[4] Zhuang Chi-jie, Zeng Rong, Zhang Bo, et al. Grounding system design method in high soil resistivity regions [J]. High Voltage Engineering. 2008, 34(5):893-897(in Chinese).
[5] He Jinliang, Kang Peng, Zeng Rong, et al. Soil structural model analysis of Wudaoliang and Tuotuohe substations for 110kV power transmission engineering of Qinghai-Tibet railway [J]. Power System Technology, 2005, 29(20): 10-14(in Chinese).
[6] Zeng Rong, Zhuang Chijie, Niu Ben, et al. Measurement of transient electric fields in air gap discharge by integrated electro-optic sensor [J]. IEEE Transactions on Plasma Science. 2013, 41(4): 955-960.
[7] Zhuang Chijie, Zeng Rong. A positivity-preserving scheme for the simulation of streamer discharges in non-attaching and attaching gases [J]. Communications in Computational Physics. 2014, 15(1): 153-178.
[8] Zhang Wenliang, Zhang Guobing. Discussion and comparison of characteristics of AC-testing supply used for UHVAC [J]. Proceedings of the CSEE, 2007, 27(4): 3-6(in Chinese).
[9] Zhuang Chijie, Zeng Rong. A local discontinuous Galerkin method for 1.5-dimensional streamer discharge simulations [J]. Applied Mathematics and Computation. 2013, 219(19): 9925-9934.
[10] Zhang Wujun, He Benteng, Shen Bing. Traveling-wave differential protection on UHV transmission line with shunt reactor [J]. Proceedings of the CSEE, 2007, 27(10): 58-63(in Chinese).
[11] Zhuang Chijie, Zeng Rong, Zhang Bo, et al. A WENO scheme for simulating streamer discharge with photoionizations [J]. IEEE Transactions on Magnetics. 2014, 50(2): 7007904.
[12] He Jinliang, Gao Yanqing, Zeng Rong, et al. Optimal design of grounding system considering the influence of seasonal frozen soil layer [J]. IEEE Trans. on Power Delivery, 2005, 20(1): 107-115.
[13] Zhuang Chijie, Zeng Rong, Zhang Bo, et al. 2-D discontinuous Galerkin method for streamer discharge simulations in nitrogen [J]. IEEE Transactions on Magnetics. 2013, 49(5): 1929-1932.
[14] Zou J, Zeng R, He J L, et al. Numerical Green's function of a point current source in horizontal multi-layer soils by utilizing the vector matrix pencil technique [J]. IEEE Trans. on Magnetics, 2004, 40(2): 730-733.
[15] IEEE std80-2000, IEEE guide for safety in AC substation grounding[S]. International Electrotechnical Commission, 2000.
[16] He Jinliang, Zeng Rong, Gao Yanqing, et al. Seasonal influences on safety of substation grounding system[J]. IEEE Trans. on Power Delivery, 2003, 18(3): 788-795.