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Impact of natural disasters on the western Hubei power grid and its anti-disaster enhancement measures

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Abstract: The western mountain area of Hubei Province has obvious vertical climate and micro-climate features. It is a place where natural disasters occur frequently. The natural disasters have recently caused several large-scale and long-time power blackouts in the western mountain area of Hubei Province. This study analyses the damage to the power grid with voltage level from 220 to 10 kV in western Hubei Province caused by natural disasters from 2008 to 2016. The influence features of natural disasters on the western Hubei power grid are researched from four aspects, including natural disaster type, grid voltage level, occurrence time of natural disaster and line outage frequency. The causes of damage to the western Hubei power grid are studied from five aspects, including grid structure, design, equipment, construction, operation and maintenance. Also, the anti-disaster enhancement measures of the western Hubei power grid are proposed from the aspects of grid planning, design, equipment transformation, construction, operation and maintenance. The research results can provide a reference for other regional power grids to carry out research on resisting natural disasters and provide a guidance to improve anti-disaster ability of the power grid.

1 Introduction

The dependence of modern society on electricity is increasing, and the demand for high-quality and reliable supply of electricity is increasing [1]. At the same time, the frequency of extremely abnormal weather caused by climate change is going up, which results in the destruction of power facilities. Natural disasters have increasing influence on safe operation of the power grid and high-quality power supply [2–6].

In recent years, there are several large-scale and long-time blackouts in Wuling and Qinba mountain areas in the west of Hubei Province during extremely natural disasters, which seriously affect the normal industrial and agricultural production and people's livelihood.

In this paper, western Hubei power grid is the power grid with a voltage level from 220 to 10 kV in Enshi, Yichang, Xiangyang, Shiyan and Shennongjia cities, which have 24 counties. The research area is located in Wuling and Qinba mountain areas, with a total area of about 76,000 km^2, accounting for about 40% of the Hubei Province's total area. The climate in the western mountain area of Hubei Province is a subtropical monsoon climate with insufficient light and abundant rainfall. It is one of the rainstorm centres in Hubei Province. Due to the large elevation difference in the western mountain area of Hubei Province, the climate is greatly affected by the terrain. It has obvious vertical climate and micro-climate features. It is one of frequent natural disaster areas in Hubei Province. For each elevation of about 100 m above sea level, the average temperature drops by 0.55°C and the rainfall increases by 35 mm.

This paper analyses the damage to the western Hubei power grid caused by natural disasters from 2008 to 2016. The influencing features of natural disasters on the western Hubei power grid are researched from four aspects, including natural disaster type, grid voltage level, occurrence time of natural disaster and line outage frequency. The causes of damage to the western Hubei power grid are studied from five aspects, including grid structure, design, equipment, construction, operation and maintenance. Also, the anti-disaster enhancement measures of the western Hubei power grid are proposed from the aspects of grid planning, design, equipment transformation, construction, operation and maintenance.

2 Damage to the western Hubei power grid caused by natural disasters

From 2008 to 2016, natural disasters affecting the western Hubei power grid mainly include ice, floods, windstorms, thunderstorms and geological disaster. The damage to the western Hubei power grid caused by nature disasters is shown in Table 1. The natural disasters cause 955 lines outage for 1471 times, four 485.3 km lines broken off and 33,808 base towers inverted and broken. The normal electricity supply of 2.005 million families is affected by natural disasters. The total loss of electricity is 18.379 million kWh. An outage occurred in both 220 and 110 kV power grids and caused load loss. The load loss is mainly caused by the outages of 10 and 35 kV lines.

2.1 Natural disaster type

The influence of different natural disasters on line outage times, the number of inverted and broken tower, and family blackout is statistically analysed, as shown in Fig. 1. Among these natural disasters, ice disaster has the biggest impact on the western Hubei power grid, followed by floods. Among those natural disasters, ice disasters cause 53% of lines broken off, 86% of towers inverted and broken, and 53% of families powered off.

2.2 Grid voltage level

The influence of natural disasters on different voltage levels in the power grid is statistically analysed from the aspects of outage line number, number of inverted and broken tower and family blackout, as shown in Fig. 2. The ability for resisting natural disasters of 110 and 220 kV power grids is strong, and of 35 and 10 kV power grids is weak. In total, family blackout of 96% is mainly caused by 10 and 35 kV line outage due to natural disasters. 10 kV lines are seriously affected by natural disasters, accounting for 85% of line outage and 99% of inverted and broken tower.

Table 1 Damage to the western Hubei power grid caused by nature disasters

Item	220 kV	110 kV	35 kV	10 kV	Sum
outage line number	32	45	69	809	955
line outage times	33	77	96	1265	1471
number of inverted and broken towers (base)	10	16	179	33,603	33,808
broken line length, km	11.1	74.3	285.5	4114.4	4485.3
family blackout	39,000	43,000	323,000	1,600,000	2,005,000
electricity loss, kWh	10,000	95,000	2,794,000	15,480,000	18,379,000

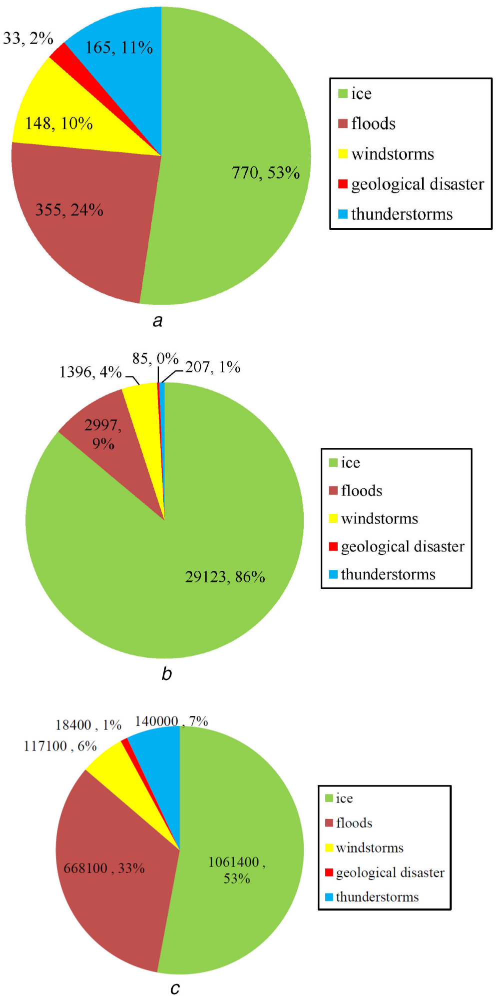

Fig. 1 *Influence of different natural disasters on the western Hubei power grid*
(a) Line outage times, ***(b)*** Number of inverted and broken towers (base), ***(c)*** Family blackout

2.3 Time of occurrence of a natural disaster

According to the time of occurrence of a natural disaster, family blackout and electricity loss caused by natural disasters are shown in Fig. 3. The power outage caused by natural disasters on the western Hubei power grid in 2016 is the most serious, followed by 2008 and 2014, because large-scale ice disaster occurred in western Hubei Province in these three years. The family blackout and electricity loss caused by natural disasters in Enshi is the most severe among the five cities.

2.4 Line outage frequency

Line outage frequency is shown in Fig. 4. Fig. 5 shows the proportion of line outage frequency at different voltage levels. A total of 949 lines were out of service during the period from 2008 to 2016 due to natural disasters. Line outage of 65% only occurred one time, 14% of line outage occurred three times and above, and 38% of line outage on 10 kV power grid occurred two times and above.

3 Causes of damage to the western Hubei power grid

The causes of damage to the western Hubei power grid are studied from five aspects, including grid structure, design, equipment, construction, operation and maintenance.

3.1 Grid structure aspect

Strong grid structure is an important foundation of power grid to resist natural disasters and to ensure the safety of power supply [7]. When line fault occurs due to natural disasters, it may cause load loss, if the line is not satisfied with the 'N−1' security criterion and the transfer load capacity of the power grid with lower voltage level is insufficient. The poor transmission capacity of the line is an important reason for load loss when the power grid is subjected to natural disasters.

From 2008 to 2016, there was one 220 kV line and one 110 kV line that caused load loss to the western Hubei power grid due to natural disasters. The 220 and 110 kV power grid structure is relatively strong. There are a total of 479 lines of 35 kV power grid on the western Hubei power grid, including 288 lines of the 35 kV power grid that do not meet the 'N−1' security criterion, and 170 lines of 35 kV power grid that do not meet the requirements of the 'N−1' security criterion, and the transfer load capacity of power grid with a lower voltage level is insufficient. A total of 69 lines of the 35 kV power grid on the western Hubei power grid faulted due to natural disasters, and 49 lines of which caused load loss.

3.2 Design aspect

Some long-running lines have a problem of low design standards. A line with low design standards involves two aspects. The first one is that the design specifications of the long-running line are low at that time. Taking distribution line as an example, the standard 'design technique regulations for overhead distribution lines with insulated conductors' (DL/T 601-1996) stipulates that the maximum ice thickness of distribution lines should be 15 mm and the maximum wind speed should be 30 m/s. The document '2016 edition of the distribution network engineering typical design of State Grid Corporation of China (SGCC)' stipulates that the maximum ice thickness of distribution lines should be 30 mm and the maximum wind speed should be 45 m/s.

The second one is that the lines are not designed based on the most harsh weather conditions, which is limited by basic historical conditions. After 2008 ice disaster, SGCC begins to carry out large-scale meteorological disasters and electricity research, including mapping of meteorological disasters [8–10]. Before 2008, there were no meteorological distribution maps with high precision, such as high-precision icing and wind speed distribution maps. Power grid was designed only with meteorological data provided by the meteorological bureau. Due to the low geographical accuracy of historical meteorological data in the early years, lines were often not designed based on the most harsh weather conditions, which made the design lower in level than actual meteorological conditions.

i. The design standard of some lines in the micro-meteorological area is low, and their ability of resisting disaster is insufficient. Some lines in the micro-meteorological area, such as the tuyere, upwind slope and ice zone, do not use a larger conversion coefficient to enhance their anti-disaster ability. There are fifteen 220 kV lines and eighteen 110 kV lines with

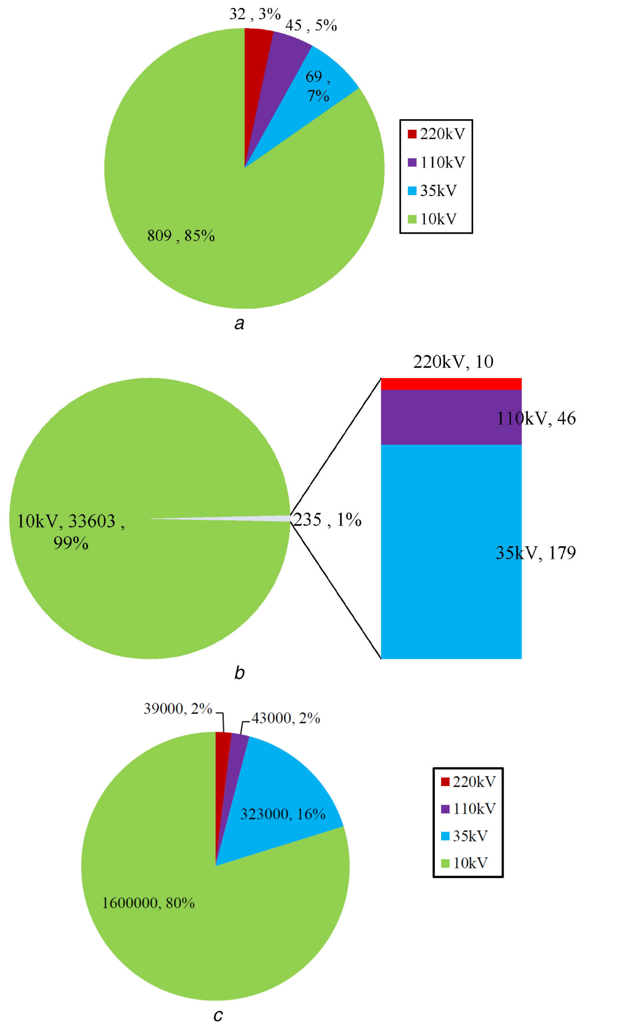

Fig. 2 *Influence of natural disasters on different voltage levels in the power grid*
(a) Outage line number, ***(b)*** Number of inverted and broken towers (base), ***(c)*** Family blackout

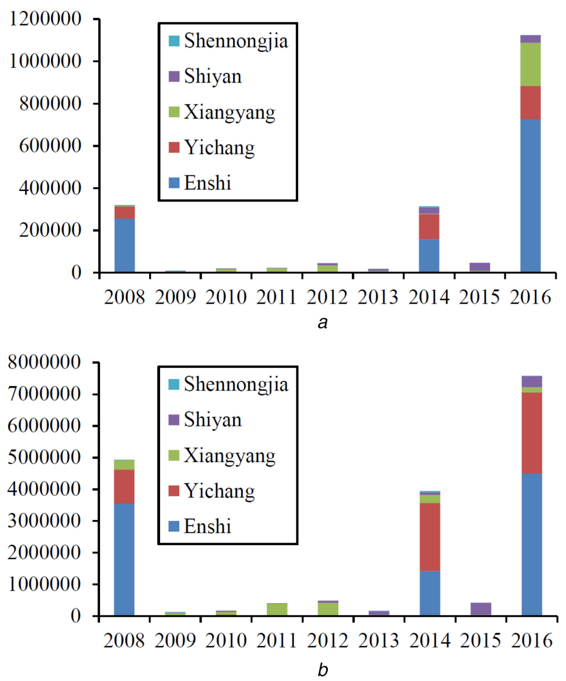

Fig. 3 *Damage to the western Hubei power grid caused by natural disasters*
(a) Family blackout, ***(b)*** Electricity loss

insufficient anti-ice ability on the western Hubei power grid. For example, the designed level of 110 kV Songhong line is three levels lower than the ice level requirements according to the document '2014 edition of Hubei power grid ice distribution map'.

ii. Some important power transmission channels adopt double circuit lines on the same tower. The power outage of these channels would have great negative influence. For example, as the important power supply lines for electric railway, part of 220 kV Jileng lines take the double circuit lines on the same tower and lay in the micro-meteorological area.

iii. All kinds of old lines are designed based on old standards that are prone to break off in natural disasters. Among 809 10 kV lines, 39% of lines operated for 15–20 years and 32.5% of lines operated for more than 20 years. 10 kV Tuansi line has operated for 42 years, and it has broken off four times due to natural disasters.

There are mainly three reasons for the breakage of 10 kV lines. The first one is that the wire diameter is too small and lacks mechanical strength. The old lines of LGJ-16, LGJ-25 and LGJ-35 are out of operation by natural disasters for 507 times, in proportion of 40.1%. The second one is that the strength of pole is not enough. 10 kV lines with wooden poles have outage 152 times. The inverted and broken wooden poles have 6418 bases. 10 kV lines with minor tip diameter poles have outage 356 times, in which the tip diameter is 130 mm and lower. The inverted and broken poles with a minor tip diameter are 12,971 bases. The third one is that the strain section is designed too long. The strain section of some lines is 1 km and above. The strain poles cannot bear the load due to ice cover and strong wind, resulting in line outage. 10 kV lines with long strain sections have outage 122 times.

3.3 Equipment aspect

The distribution network in some areas of western Hubei Province was built in the 90s of the last century, especially in some high altitude and remote mountainous areas. Subject to technical standards, investment scale, transportation and other factors at that time, the equipment is old and its manufacturing standards are not high. The lines with old equipment are more prone to break off in the face of natural disasters.

i. Some lines in the heavy lightning area do not carry out lightning protection transformation in time. Also, lightning can cause lines fault trip. In total, 15.45% of 10 kV lines on the western Hubei power grid are located in the lightning area with C1 level and above, where C1 level means the ground flash density is larger than 2.78 times/(km^2 a). 10 kV lines have outage 125 times due to no protective measures installed.

ii. Some old insulators and fittings with insufficient mechanical strength are not changed timely. Some line towers and poles have various problems such as serious weather and cracks due to the long-time operation.

3.4 Construction aspect

The operation time of equipment in the western Hubei power grid is generally long. As the standard construction level of distribution network is low at that time, the construction quality is also not high, which leads to low disaster resistance of individual line equipment. After a long period of operation, those lines are prone to break off when they suffer from natural disasters such as snow, flood, strong wind and landslide. The buried depth of some towers is not enough. Some tower chucks may be not installed as required. When soil is soft and geological condition is not good, concrete foundation should be poured.

3.5 Operation and maintenance aspect

i. The online icing monitoring system is insufficient. The de-icing and melting ice equipment is not enough. At present, the number of icing condition monitoring devices in the Hubei

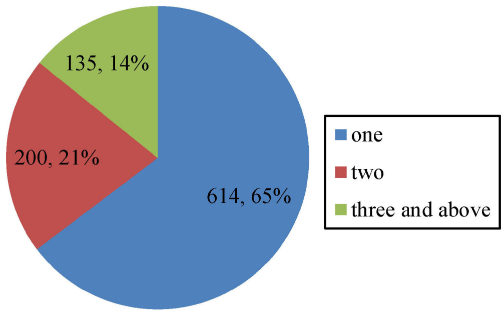

Fig. 4 *Line outage frequency*

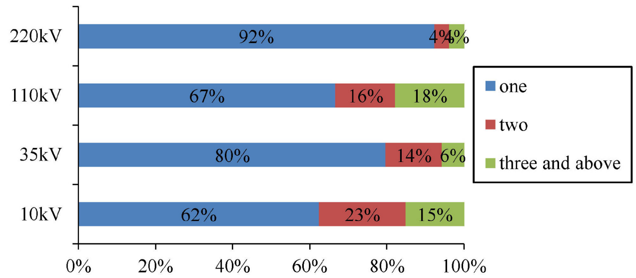

Fig. 5 *Proportion of line outage frequency at different voltage levels*

power grid is small and manual inspection is still mainly relied on. The online icing monitoring system needs to be improved. The means of de-icing and melting ice are still limited. Manual de-icing is mainly used. Only the 500 kV Xianning substation is equipped with a set of direct current ice melting equipment. The 500 kV Enshi substation is under construction with fixed-type direct current ice melting equipment.

ii. The emergency equipment is inadequate that restricts efficient repair. Under bad weather, such as freezing, rain and snow, the performance of existing emergency repairing vehicles is difficult to meet the demand. In the repairing process, four wheel drive vehicles are relied in order to reach through high mountain roads and icy roads. The high-performance vehicles that are suitable for mountain rush repair and transportation are inadequate.

iii. The transmission lines on the western Hubei power grid are mostly located in the mountainous area, and line channel overlaps with local dense vegetation forest. If line channel maintenance wrecker work is not timely, it is easy to cause line channel very close to the adjacent trees. Natural disasters, such as snow and strong wind, can easily cause adjacent trees to collapse, which would lead to short-circuit failure and line outage.

4 Anti-disaster enhancement measures of the western Hubei power grid

The anti-disaster enhancement measures of the western Hubei power grid are proposed from the aspects of grid planning, design, equipment transformation, construction, operation and maintenance.

4.1 Grid planning aspect

i. For 110 kV and above grids, if there is no 220 kV substation or the 220 kV substation that is only fed by single line for long distance, it is suggested to strengthen the 110 kV and above power grid structure by increasing the number of substations and building a new 220 kV transmission channel.

ii. It is suggested to increase the number of 110 kV substations or build new 35 kV power supply channel in areas where power outages occur due to natural disasters when a 35 kV line singly radioactively feeds two 35 kV substations and above. There are four 35 kV lines that have outage and singly radioactive feed three 35 kV substations, including the 35 kV Jianchang line in Enshi. Twelve 35 kV lines have outage and singly radioactively feed two 35 kV substations, such as the 35 kV Gaolong line in Enshi.

iii. It is suggested to build new power supply channels or transform the existing lines for the lines outage two times and above and cause a wide range of users' outage. From 2008 to 2016, there are fifteen 35 kV lines outage for two times and above. The 35 kV Songjiaping line has outage for 11 times in Shennongjia area.

iv. For some areas with 10 kV lines that are singly radioactive feeding two 10 kV stations and above or power outage three times and above, and causing power outages, it is suggested to add the 35 kV distribution substation or transform the existing lines. From 2008 to 2016, there are 182 10 kV lines broken off for two times and 135 10 kV lines broken off for three times and above by natural disasters on the western Hubei power grid.

v. It is suggested to strengthen the connection between 10 kV stations, balance line load rate reasonably and improve power transfer capability. The problems of long line, small segment and low contact rate can be solved by assembling the section switch and contact switch. Reasonable balance subsection branch line with distribution transformers' capacity can reduce fault outage range and influence. Gradually installing circuit breaker, drop insurance, isolation knife and other operational isolation equipment in the beginning of the branch line can facilitate isolation of fault branch, as soon as it is possible to restore the main line power transmission.

4.2 Design aspect

i. The transmission lines in the area of elevation over 800 m should have a differentiated design. The path selection of the new line should try to avoid heavy ice area, easy galloping area and easy iced terrain, such as tuyere, pass, yamaguchi and lake [11]. The anti-ice and anti-galloping technical specifications should be implemented.

ii. For 10 kV distribution lines located in disaster areas, it is recommended that the cross-sectional area of the wire should be no <50 mm^2. For medium- and heavy-ice areas, flood-prone areas, above 9th-grade gale areas and geological disaster areas, it is recommended to use steel core insulated wires or aluminium cable steel reinforced with a cross-sectional area of no <95 mm^2; the cement rod uses non-prestressed poles with high strength, whose tip diameter is not <190 mm, and tension section should not exceed 500 m. Individual prone disaster areas can be calculated according to the regulations, raising the standards of tip diameter and tension section. Insulated conductors or local section cables need to be taken into account the hazard risk areas with multiple dumped trees.

iii. For minefields and strong minefields, considering the grade of minefield, the importance level of lines and the failure conditions of historical mine damage, lightning protection level of distribution lines should be gradually strengthened according to the actual situation and operation experience. It is recommended to install line-type arresters or lightning protection fittings by each rod in the lightning disaster area.

4.3 Equipment transformation aspect

i. The anti-ice transformation of transmission lines is promoted to improve anti-ice ability. The anti-ice design review and transformation should be carried out from the aspects of ice zone division, tension section setting, tower structure, ground wire type, insulator string, fittings strength etc.

ii. The technical transformation of transmission line in flood detention basin should be strengthened. The section of transmission line in flood detention basin should be checked from the aspect of tower foundation design and conductor clearance distance. The line section should be transformed if its tower design does not take flood impact and the suitable conductor clearance distance into account.

iii. The technical transformation of lines located in the landslide zone and collapse section are promoted. According to the site conditions and assessment results, the towers located in serious soil erosion and landslide areas should take some measures, such as reinforcing foundation, building retaining walls, cutting ditches and constructing slope protection, meanwhile considering the relocation of the lines if necessary.

iv. According to the latest design and material standards, for medium- and heavy-ice areas, flood-prone areas, above 9th-grade gale areas and geological disaster areas, lines need to be gradually replaced if the situations exit as follows: non-prestressed poles, wood poles, wires with cross-sectional area less than 50 mm^2, tip diameter less than 190 mm and tension section exceeding 500 m.

v. Equipment hidden danger rectification work should be gradually promoted if towers have conditions as follows: insufficient depth, non-solid foundation, no tower chuck and concrete foundation.

4.4 Construction aspect

i. The technical supervision of the whole construction process should be strengthened. The tower and line engineering inspection and acceptance should be strengthened, in strict accordance with the relevant requirements of tower construction, to ensure the depth of the tower meet the requirements.

ii. The construction should fully consider local geological environment and meteorological conditions. If the overturning moment of cement rod is greater than anti-overturning moment of original undisturbed soil, the chuck should be installed.

iii. In case of loose soil, quicksand and high groundwater level, reinforcement rod-based measures should be taken, such as adding chucks, herringbone cables and pouring concrete foundation.

4.5 Operation and maintenance aspect

i. In various kinds of major disaster areas, operation and management of lines should be enhanced. The line section in disaster-prone areas is divided, according to the operation experience. In accordance with the relevant operation and maintenance regulations, all or part of the equipment should be inspected under severe weather conditions, such as gale, heavy rain, icing, high temperature etc. Also, the priority inspection objects are tower, foundation, wire, cable and pulling line.

ii. Attention should be paid to dense vegetation areas overlapping with the disaster areas such as strong wind, ice and snow. The trees at the power transmission routine should be cleaned up to avoid secondary disasters caused by trees overlaying the line due to natural disasters. For the conventional vegetation area, the minimum horizontal distance between trees and lines should be >2 m and the minimum vertical distance should be >1.5 m. For areas prone to disaster, super-tall trees and vegetation areas, the distance standards should appropriately widen, taking into account the height of adjacent pine trees as a safe reference distance.

5 Conclusion

i. The natural disasters cause 955 lines outage for 1471 times, 4485.3 km lines broken off, 33,808 base towers inverted and broken. The normal electricity supply of 2.005 million families is affected by natural disasters. The total loss of electricity is 18.379 million kWh. The ice disaster causes the biggest impact on the western Hubei power grid, followed by floods. In total, 35% of the outage lines occur outage two times and more.

ii. The 220 and 110 kV power grid structures are relatively strong. The load loss is mainly caused by outages of 10 and 35 kV lines. The poor transmission capacity of the lines is an important reason for load loss when the power grid is subjected to natural disasters.

iii. The causes of damage to the power grid due to natural disasters can be studied from five aspects, including grid structure, design, equipment, construction, operation and maintenance. Also, the anti-disaster enhancement measures of power grid can be proposed from the aspects of grid planning, design, equipment transformation, construction, operation and maintenance.

iv. The research results can provide a reference for other regional power grid to carry out research on resisting natural disasters and provide a guidance to improve anti-disaster ability of power grid.

6 References

[1] Luo, Z., Dong, Y., Hu, C.: 'Analysis of state grid security in 2008', *Electr. Power*, 2009, **42**, (5), pp. 8–12

[2] Chen, C., Wang, J., Ton, D.: 'Modernizing distribution system restoration to achieve grid resiliency against extreme weather events: an integrated solution', *Proc. IEEE*, 2017, **105**, (7), pp. 1267–1288

[3] Araneda, J.C., Rudnick, H., Mocarquer, S., *et al.*: 'Lessons from the 2010 Chilean earthquake and its impact on electricity supply'. Proc. Int. Conf. Power System Technology, Hangzhou, China, October 2010, pp. 1–5

[4] Hines, P., Apt, J., Talukdar, S.: 'Trends in the history of large blackouts in the United of States'. Proc. IEEE Power Energy Society General Meeting, Pittsburgh, USA, July 2008, pp. 1–8

[5] Chen, P., Cao, B., Luo, X., *et al.*: 'Operation data and feature analysis of the main natural disasters of power network in China', *Electr. Power*, 2014, **47**, (7), pp. 57–61

[6] Tang, S., Zhang, M., Li, J., *et al.*: 'Review of blackout in Hainan on September 26th – causes and recommendations', *Autom. Electr. Power Syst.*, 2006, **31**, (1), pp. 1–8

[7] Chen, Q., Yin, X., Hou, H., *et al.*: 'Analysis on power system structure defect from snow disaster point of view in China southern area in 2008', *Electr. Power*, 2008, **41**, (12), pp. 1–5

[8] Huang, J., Tan, B., Chen, X., *et al.*: 'Spatiotemporal distribution of lightning disasters of power lines in Hubei province using data mining based on a priori association rules', *J. Appl. Sci.*, 2017, **35**, (1), pp. 31–41

[9] Li, T.: 'Establishment and implementation of anti-typhoon technique system in CSG', *Distrib. Utilization*, 2016, **33**, (9), pp. 2–5

[10] Liu, M., Li, Y., Zhang, H., *et al.*: 'Safety analysis of typical transmission tower in geologic disaster zone', *Electr. Power*, 2012, **45**, (5), pp. 34–38

[11] Hu, Y.: 'Analysis and countermeasures discussion for large area icing accident on power grid', *High Volt. Eng.*, 2008, **34**, (2), pp. 215–219