Climate Disasters, Grid Outages and Economic Losses

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Abstract. This paper assesses the far-reaching economic and social impacts of large-scale power outages on the power grid caused by frequent extreme weather events in the context of global warming. The direct and indirect losses of the large-scale blackout on the society and economy, including casualties and enterprise economic losses, were analyzed, and a comprehensive loss index system was proposed. The paper established an assessment model and quantitatively analyzed the economic losses caused by the blackout through questionnaire survey and data collection. The results show that the direct economic loss caused by the power outage is proportional to the electric load, in which the secondary industry is affected the most, while the primary industry is affected the least. The arithmetic analysis assesses the economic losses under average and maximum daily loads based on 2019 data, and finds that the losses are particularly severe in the third quarter due to high power loads. The paper provides a scientific basis for the government and power companies to respond to major power outages, and is of great significance for building a new type of power system and ensuring social and economic stability.

Keywords: climate disaster, grid blackout, economic loss assessment.

1 Introduction

In recent years, as the global climate continues to warm and the natural environment deteriorates, the number of natural disasters and extreme emergencies has been increasing year by year. Typhoons, rainstorms, freezing rain and snow, and other small-probability, high-risk natural disasters not only cause large amounts of equipment damage in a short period of time, but also increase the difficulty of system restoration, leading to large-scale and prolonged power outages. As the power grid is an important transmission medium connecting power producers and consumers, large-scale, widespread power outages on the grid will lead to factory shutdowns, communication disruptions, lighting shortages and other problems, bringing great negative impacts on people's lives, economic development, and social stability.

On the one hand, the blackout caused significant economic and political losses, and seriously affected the normal operation of various fields such as communications, medical care and transportation; on the other hand, it posed a threat to the lives, properties

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and environmental safety of the public, and greatly jeopardized the public health of the societ.

China's reverse distribution of energy resources and the rapid growth of power demand determines the construction of ultra-high voltage power grid to achieve regional interconnection has become an inevitable trend, once the blackout not only suffered major losses, but also to social security and stability, economic development and people's lives with unpredictable consequences [1]; the complexity of the modern power system determines the impact of grid accidents in a wide range of fast speed of the waves. Therefore, in-depth study of the direct economic losses of large-scale power outages, not only helps the development of social economy, but also helps to reduce the social and economic impact of large- scale power outages, for the future of the government and power companies to deal with large-scale power outages in a timely manner to take scientific countermeasures to provide reference significance, to help the construction of a new type of power system.

2 Literature Review

2.1 Socio-Economic Impact of Major Power Outages

The economic losses to society caused by the blackout can be categorized into direct and indirect economic losses according to the mode of impact [2].

Many scholars have studied the losses and impacts of major power outages on society from both qualitative and quantitative perspectives. Guo [3] elaborates that the United States and Canada, Britain and other western countries adopt the user survey method to get the data of blackout loss of different types of users, and calculate the relationship between the value of blackout loss and the average price of electricity. Wang et al. [4] proposes the outage loss survey method suitable for China's electric power users, introduces in detail the steps of questionnaire survey method and the specific content of the user questionnaire, statistically analyzes the survey results, and establishes the model of the user's outage loss. Bai et al. [5] design different types of user questionnaires, a region of China after the survey to obtain industrial and commercial, residential and other power outage loss data, using statistical analysis to calculate the value of the region's user power outage loss. Liu et al. [6] proposes a method of estimating the loss function of power outage of users based on the average benefit of power users per kWh of electricity consumed in the studied area with reference to the loss function of power outage in other regions. A comprehensive customer outage loss function that expresses the relationship between comprehensive customer outage loss and outage duration is established to estimate the comprehensive outage loss of each type of customer, which provides a basis for electric power enterprises to improve the reliability of urban power grids and optimize the allocation of emergency power supply in terms of investment and decision-making. Liu et al. [7] proposes the classification method and loss assessment index construction principle of the comprehensive social loss of power outage from the basic theory of accident economic loss, and constructs

the comprehensive social loss assessment index system of power outage from the aspects of casualties, power supply department and power users' economic loss, and indirect economic loss of power outage.

2.2 Methods and Models Related to the Study of Major Power Outages

Wang & Han [2] briefly analyzes the common features and problems of accidental loss assessment theories and methods at home and abroad, defines the concept and calculation range of accidental economic loss more clearly. Most methods and models under the research of current scholars can be realized to estimate the loss of power outage of a certain type or several types of power users, such as the constructive function method, the method of electricity production ratio and the method of converted multiples of average electricity price. Liu et al. [6] investigated the average economic benefits corresponding to the consumption of 1kWh by the users in the region to be studied, and substituting into the existing blackout loss function. Li et al. [8] thinks that the study of distribution network blackout loss lies in determining the economic loss function of different types of power users. Wang et al. [9] establishes the index system for evaluating the impact of power outage and its support system in terms of the scope of power outage, power outage users, power outage duration, and power outage loss. Lin et al. [10] proposed a comprehensive assessment method for the impact of user blackout and established an index system for the impact of user blackout. Cai and Zhang [11] derived the relationship between short-time power outage time and economic losses in the city, revealing that short-time power outage losses have the characteristics of frequency, randomness, and large impact losses on sensitive users.

On the basis of comprehensive losses caused by a large blackout in an actual power grid, Liu et al. (2014) [12] establishes a social loss assessment index system and quantitative model for power outage based on the social public security model, and establishes a social loss assessment index system and quantitative model for power outage from the aspects of social casualty loss, property loss and delay loss.

3 Methodology

3.1 Factors Affecting and Calculation of Direct Economic Losses Due to Major Power Outages

The direct economic loss mainly includes: property loss, engineering facilities loss, resource loss, environmental loss, casualty loss and accident rescue cost [13]. The direct economic loss caused by the blackout mainly includes the economic loss of the power supply department and the economic loss of power users [14-16]. The main factors affecting the economic loss of power outage include: economic loss of users, price of electricity for users, power load and duration of power outage [17, 18].

The formula for calculating the direct economic loss of the power supply sector for a major blackout is:

$$C_D = \sum_{e=1}^{4} S_e Q_e \, t \tag{1}$$

The relevant variables in the equation are explained as follows: e=1,2,3,4 are agricultural, industrial, commercial and residential users in the blackout area, respectively; Se is the tariff for category e users (unit: yuan/kWh); Qe is the lost load (i.e., the amount of load cutting, unit: MW) of category e users; and t is the duration of the blackout (unit: h).

The formula for calculating the direct economic losses of power users in a major power outage is:

$$C_Y = \sum_{e=1}^{4} Q_e C_e \, t \tag{2}$$

Given that the research object of this paper is the economic loss caused by power outage, only the duration of power outage is taken into account in the model setting, and the model is revised as follows with reference to the research model of Liu et al.(2014).

3.2 Questionnaire Design and Data Processing

In this paper, a questionnaire was used to obtain the data required for the study. The questionnaire was released anonymously online, with three parts of questions: basic information, personal/family losses, and business losses. A total of 182 responses were collected, and the main data collected from the questionnaire are described below:

Figure 1, Figure 2 shows the results of the survey on direct economic losses of individuals and families. The questionnaire covers 25 provinces and municipalities directly under the central government, of which Beijing has the highest frequency of 29, which is a more comprehensive coverage.

In terms of personal losses, the respondents generally agreed that the blackout had an impact on their personal lives, but not too much (45.6%), but 11.54% of the respondents still indicated that the blackout would cause direct economic losses to them, with the amount of direct losses as a percentage of the total amount as shown below:

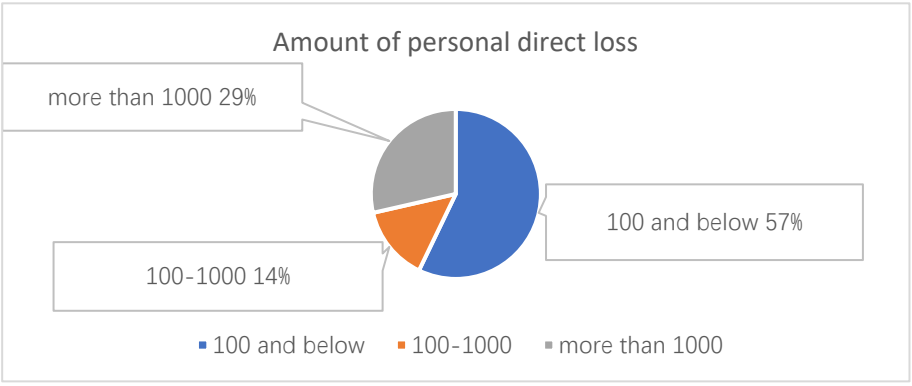

Fig. 1. Statistics on the amount of direct economic losses of individuals

The findings show that the economic loss of households due to major power outages comes mainly from food spoilage, etc. due to prolonged power outages, and to a lesser extent, the value of other alternatives consumed as a result of power outages

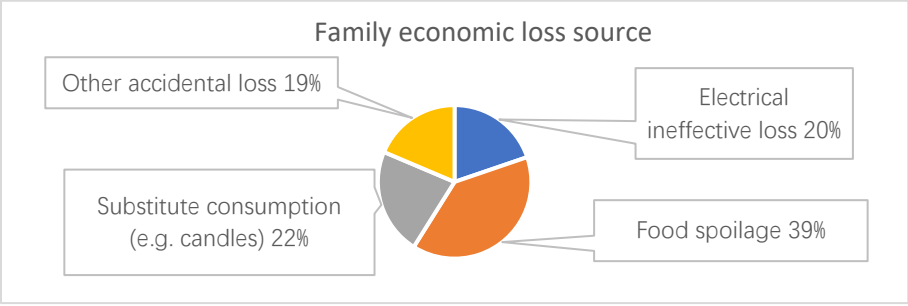

Fig. 2. Categorized statistics on the sources of economic losses of households

The respondents generally agreed that the economic impact of the blackout on their individuals/families was within acceptable limits, but still about ten percent of the respondents felt that the given items had a great impact on them, and the items with a greater impact were mainly price increases, inconvenience in living, increase in daily expenditures due to the blackout (43.96%), and damage to the operation of businesses (36.26%).

Only 59.89% of the respondents know the information about the storage and use of the emergency power supply or alternative power supply in their enterprises. 47.8% of the respondents believe that the impacts of power outage on the enterprise mainly come from "affecting the normal operation of the enterprise and causing adverse impacts on the society", followed by "causing the loss of important data" (28.2%) and "major property damage" (23.63%). caused loss of important data" (28.2%) and "major property damage" (23.63%).

In the estimation of the loss caused by the blackout, the respondents generally believed that this loss would come from the delay of production materials and the shutdown and damage of production equipment caused by the blackout.

Average duration of power outage: 166 valid questionnaires were obtained from this question, with a duration range of 0-30 hours, and the mean value of duration was 9.22 hours, with the median and the plural being 2 hours. Among them, 30 valid questionnaires from Beijing are organized with the question of the region, the duration range is 0-12 hours, the mean value of the duration is 3.75 hours, and the median and the plural are both 1 hour.

Synthesizing the results of questionnaire collation and the reality, this study adopts the average outage duration of 3.11 hours/household in the first three quarters in major cities published by the National Energy Administration in 2020 as the data source of this paper. The duration of power outage is selected to be 1 hour per quarter, with a total of 4 hours of power outage for the whole year.

The electricity prices of primary, secondary and tertiary industries and residential users in different regions are all organized through the State Grid platform query, and

the data are all based on the August 2022 implementation price. Among them, the primary industry is dominated by agriculture, with a total of 23 provinces/municipalities/autonomous regions counting the ladder tariffs, and the average value tariffs are derived through the weighted average method. The agricultural mean electricity price is highest in Shanghai at 0.6820 yuan/kWh and lowest in Xinjiang at 0.2595 yuan/kWh.

The direct economic loss data of the user is collected and organized through the questionnaire, the survey indicates that the major power outage makes the individual produce direct economic loss of the respondent users accounted for 11.54%, the statistics obtained the amount of the loss ranges from 0 to 1500 yuan, which indicates that the amount of the loss of the largest number of respondents less than or equal to the amount of 100 yuan, accounting for 57.

4 Example Analysis

Considering that the latest load curve released by official channels is 2019 (https://www.ndrc.gov.cn/?code=&state=123), the direct economic loss arithmetic example calculation in this study is selected to be calculated in 2019. On the basis of the above model design, this paper takes the national average daily load as the basis of loss load calculation, respectively, and carries out the arithmetic example analysis of the comprehensive social loss assessment model of the major power outage.

1. Comprehensive social losses

As shown in Figure 3, the gross national product in 2019 was 990,865,510,000,000 Yuan, and the above model calculates that the total comprehensive social loss caused by the big blackout in the same year was about 90,900,000,000 Yuan, which accounted for about 0.0918% of the gross product. In 2019, the gross product of China's primary, secondary, and tertiary industries accounted for 7.11%, 38.97%, and 53.91%, respectively, and the total share of secondary and tertiary industries was 92.89%, and the tertiary industry exceeded the secondary industry by 14.94%. ratio is 92.89%, and the tertiary industry exceeds the secondary industry by 14.94%, as can be seen from the industrial structure, China's economy is well developed and highly dependent on electricity.

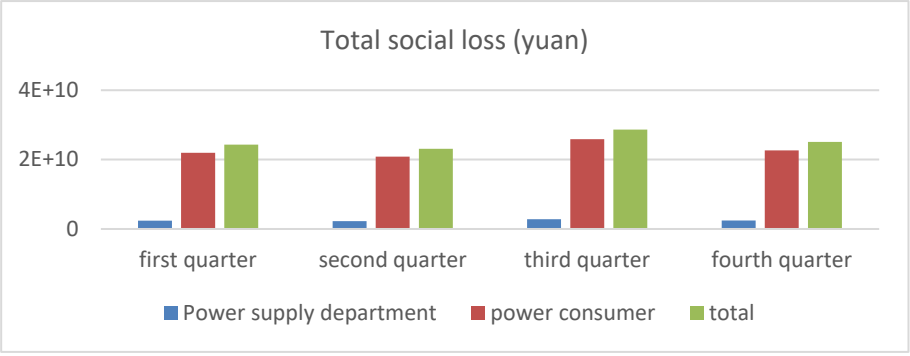

Fig. 3. Combined social losses due to major power outage

The economic loss from the power supply department is mainly the reduction of electricity revenue caused by the blackout, which is directly related to the value of electricity load, accounting for about 9.72% of the comprehensive loss of society; the economic loss from the power users, including the units and individuals who consume electricity through the grid, is mainly the impediment to the production and living process caused by the blackout, such as delay in the means of production as well as the shutdown and damage of the production equipment, whose value accounts for about 90.28% of the comprehensive loss of society. The value of this loss accounts for about 90.28% of the total loss in society.

2. losses in the electricity sector

As shown in Figure 4, the economic loss to the power supply sector caused by the major blackout in 2019 was about 8.847 billion yuan, of which the economic loss from the primary, secondary and tertiary industries and urban and rural residents was 2.061, 2.136, 2.728, and 1.922 (billion yuan), respectively.

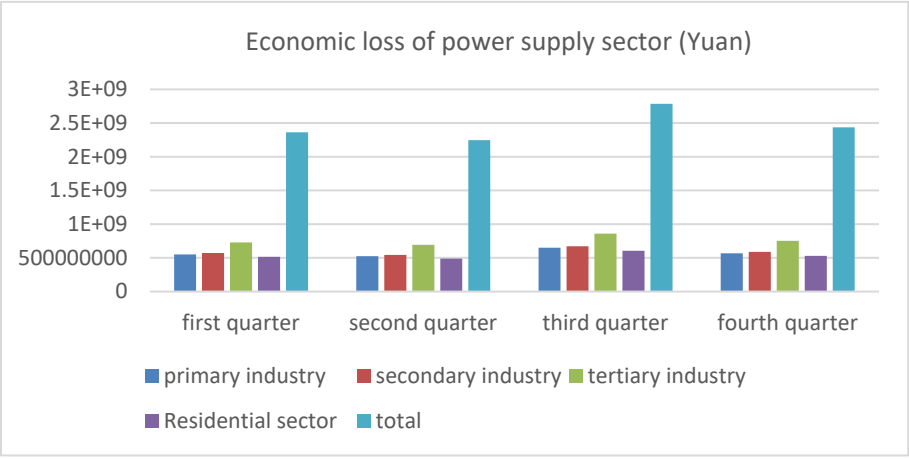

Fig. 4. Economic losses in the power sector due to major power outages

The economic loss from the power supply sector reaches the highest in the third quarter, which is about 2.499 billion yuan, accounting for about 28.24% of the annual economic loss from the power supply sector. The proportion of economic losses in the power sector from the primary, secondary, tertiary and residential sectors is relatively close. Among them, the tertiary sector accounts for the highest proportion of 30.83%, while the urban and rural residential sector, which accounts for the lowest proportion, also reaches 21.72%. Since the economic loss of the power supply sector mainly comes from the reduction of electricity revenue caused by the power outage, the value of this loss is directly related to the power load and the price of electricity for users.

3. Economic losses of electricity users

The economic loss caused by the major blackout to electric power users in 2019 was about 82.128 billion yuan, of which the economic loss from the primary, secondary and tertiary industries as well as urban and rural residents was 8.828, 32.963, 26.684, and

13.653 billion yuan (billion yuan), respectively. Similar to the economic losses of the power supply sector, the economic losses of electric power consumers also reached the highest in the third quarter, about 23.193 billion yuan, accounting for about 28.24% of the annual economic losses of the power supply sector.

The economic loss of the secondary industry reaches 40%, which is much higher than that of other sectors of electricity users, and the primary industry has the lowest percentage of loss, which is only 11%, and in general, the loss of each sector possesses a certain gap. China has entered the stage of high-quality economic development, and the proportion of the gross domestic product of the primary industry in 2019 was only 7.11%, in addition, although agriculture has entered the era of mechanization, but compared with other sectors, the dependence of agriculture on electricity is relatively low, and thus the loss of electric power users from the primary industry when the blackout occurs is only 8.828 billion yuan.

In 2019, the loss of electric power users in the secondary industry reached 32.963 billion yuan, and the loss of the secondary industry is mainly for large industrial users. billion yuan, the secondary industry is mainly large-scale industries, characterized by high power consumption and large capacity, and has the highest degree of dependence on electricity. Once a power outage occurs, it may cause serious accidents such as leakage of hazardous materials and large explosions, in addition to causing delays in production activities, shutdown of production equipment and destruction of production materials.

5 Conclusions

The direct economic loss of the blackout is divided into the economic loss of the power supply department and the economic loss of the power users, both of which are positively correlated with the power load. On the one hand, under high power load, the same duration of blackout will cause the power supply department to lose more income from electricity bill; on the other hand, high power load means high power demand, and thus the impediment of blackout to the production and life process of the power users is higher than that of other periods.

In terms of economic losses to electricity users, the secondary sector has much higher economic losses than the other sectors, and the primary sector has the lowest percentage of losses. Agriculture has a lower dependence on electricity, so the loss of electricity users from the primary sector is the lowest when blackout occurs. The secondary industry is mainly large-scale industry, characterized by high power consumption and large capacity, and has the highest degree of dependence on electricity, thus it suffers the highest economic losses.

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