Research on Standardization of Power Grid Operation Safety Management Based on Set Theory

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Abstract. In order to solve the problems in current power grid operation safety management field, the paper firstly distinguishes the concept definitions and forms the uniform standards by discriminating the basic concepts in safety management field. Then, the extension model is formed through standardizing the relationship between different terms by using Wayne diagram based on the set theory. Finally, a set of concept identification algorithm flow is proposed to help the identification of concepts in actual practices. The research shows that, from the perspective of accident causation, the safety management concepts can be divided into two categories. In terms of the causation, the accident potential belongs to the hazard of second kind and third kind which is included into the risk; in the results caused by the causation, the accident precursor includes the near-miss and the accident without intervention which are included into the incident.

Keywords: Power grid operation; safety management; accident; potential risk; hazard; precursor; Venn diagram.

1. Introduction
With the acceleration of the power construction, the scale of power grid is continuously expanded and the structure of power grid is more complex, resulting that there are increasing risks for the power grid operation [1]. Therefore, the safety management for the power grid operation has attracted more and more attentions. In addition that the power enterprise focuses on reducing the accidents and guaranteeing the safety and effectiveness of the power grid operation, the government has released the important instructions on the safety management of the power grid operation [2]. However, at present, China has not formed the standardized safety management concept system of the power grid operation and has not clearly defined some basic safety management concepts. Hereby, the focus of the paper is to form a set of standardized safety risk management concepts system of the power grid operation and express the logic relationship between concepts based on the set theory.

Chen Baozhi [3] and Tian Shuicheng [4] investigated the definitions and classifications of hazard respectively from the perspective of the hazard of second kind and third kind. Meng Xiaofei et al [5] redefined the hazard and analyzed the relationship between the accident potential and the hazard, considering that the accident potential is one of the hazards in unsafe status. In addition, Cavalieri et al [6] discriminated the definitions of terms, such as fault, accident, incident and near-miss, by using the
set theory, and put forward the extension model which can distinguish the range of terms concepts. Lei Changqun [7] applied the identification of safety management concepts for improving the dual system of risk classification management and control and potential risk troubleshooting and governance. What’s more, Dong Yuncan [8] analyzed the hazards included in the power grid risks and the personal risks in the power industry. From the perspective of accident causation, the above researches mostly focus on a certain aspect of causation factors and causation results, which are short of the discrimination for concepts in different levels. Therefore, the paper will comprehensively discriminate the safety management concepts of the power grid operation from the causation aspect and the result aspect, thereby analyzing the difference between different concepts and the relationship between different levels. Set theory is the basic theory for studying the logical relationship between concepts. The Wayne diagram can intuitively show the relationship between different sets and can be used to study the internal logical relationship between concepts. Nicholas devoted to a summary, intended for the working analyst, of the extensive background in set theory [9].

The paper firstly distinguishes the concept definitions and forms the uniform standards by discriminating the basic concepts in safety management of the power grid operation. Then, the extension model is formed through standardizing the relationship between different terms by using Wayne diagram based on the set theory. Finally, a set of concept identification algorithm flow is proposed to help the identification of concepts in actual practices.

2. Theoretical Discrimination

2.1. Discrimination of Incident, Accident, Near-miss and Precursor

Ref. [10] issued by National Safety Council of the United States indicates that the incident refers to the unplanned and unexpected condition that may have adverse effect on the completion of task and may cause personal injury or other losses. The above statements emphasize that the incident, with the unplanned property, may occur the unplanned condition, while the accident is included in the incident and must cause certain loss. The Interim Provisions on the Investigation of Electric Power Generation Accidents divides the accident in the power industry into three categories, which is the personal accident in power production, the accident in power grid operation and the equipment accident in power production. The power grid operation accident is divided into tremendous devastating accident, considerable accident, serious accident and ordinary accident in accordance with five indicators, such as supply reduction loan of power grid, number of power-off users and power-off duration. Except for the above accidents in four levels stipulated nationally, the Investigation Procedures of Safety Accidents of State Grid Corporation of China divides the safety accident into eight levels with additionally adding the accident in five levels to eight levels [11].

The Occupational Health and Safety Assessment Series consider that the incident which does not cause the occurrence of damage or disaster also can be called as “near-miss” or “near-hit”. The Accident Precursor Analysis and Management issued by the National Academy of Engineering of the United States in a seminar specifically analyzed the significance of the accident precursor for the safety management [12]. From the perspective of overall situation, if an accident which has occurred fails to be improved and implemented, with the passage of time, the other similar accident may be caused under the catalysis of deterioration factor. Therefore, this kind of accident is a kind of precursor. Since the same kind of condition exists in the power grid operation [13], it shall include the concepts of near-miss and precursor into the safety management of power grid operation.

The accident in power grid operation is divided into the accident in eight levels in accordance with a series of indicators, such as the supply reduction load of power grid, and the accident precursor includes near-miss and part accident.

2.2. Discrimination of Risk, Hazard and Accident Potential

OHSAS defines risk as the combination of harms or the possibilities of occurring damages, and the severity of the possibilities of occurring damages. According to the above definition, the power expert Vittal [14] put forward the formula definition of the risk in power grid operation, that is, the risk in power grid operation is the product of the severity of occurred risk multiplying by its probability. The
Management and Control Measures for Power Grid Safety Risk issued by National Energy Administration of the People’s Republic of China classify the power grid security risks in accordance with the consequences that may be caused by the risks [15]. Therefore, the risk emphasizes a kind of possibility or uncertainty and the resulting potential influences. Since anything that human beings engage in can cause risk which cannot be totally eliminated with any means, the risk is an objective existence.

According to the theory of hazard of third kind, Chen Quan [16] considered that the accident potential is the hazard of second kind and third kind, which includes the unsafe behavior of human beings and the unsafe condition of materials and the defective management which induces the above two factors. Therefore, the definition of the hazard in power grid operation can be summarized as the combination of sources, conditions and behaviors which cause the incidents in power grid operation.

Potential risk is usually known as accident potential in China. According to the Interim Provisions on Supervision and Management of Power Safety Potential (hereinafter referred to as the Provisions), it can summarize that the accident potential in power grid operation refers to the unsafe behavior of human beings, the unsafe condition of materials, the adverse environment and the defective management produced in power grid operation that affect the safe and stable operation of power grid. The unsafe behavior of human beings is the human error that may cause the accident, and the unsafe condition of materials is defined as the material condition that may cause the accident. In addition that the defective management is included into the definition of the accident potential, it shall always need to consider the adverse environment in the actual production operation. In addition, the risk cannot be completely eliminated, while the accident potential can be eliminated with achieving the goal of reducing risk [17].

3. Concept Standardization

3.1. Unify Definitions of Concepts

Incident refers to the unplanned and unexpected condition that may affect the stable operation or normal power supply of the power system in the power grid operation, which is represented with \( A \).

Accident refers to the incident caused in the power grid operation which may affect the stable operation or normal power supply of the power system such as the supply reduction loan of power grid and power-off for users, which is represented with \( B \). It includes:

1. Tremendous devastating accident which is represented with \( B_1 \).
2. Considerable accident which is represented with \( B_2 \).
3. Serious accident which is represented with \( B_3 \).
4. Ordinary accident which is represented with \( B_4 \).

Accident precursor refers to an incident or condition, which is represented with \( C \), and if a series of behaviors or situations are slightly different, a series of similar incidents will be resulted.

Near miss refers to the incident caused in the power grid operation which does not affect the stable operation or normal power supply of the power system such as the supply reduction loan of power grid and power-off for users, which is represented with \( D \).

Risk refers to the combination of the possibility of occurring the power grid accident and the severity of consequence, which is represented with \( \Omega \).

Hazard refers to the combination of sources, conditions and behaviors which cause the incidents in power grid operation, which is represented with \( E \).

Accident potential refers to the unsafe behavior of human beings, the unsafe condition of materials, the adverse environment and the defective management produced in power grid operation that affect the safe and stable operation of power grid, which is represented with \( F \).

Adverse environment refers to the potential dangerous factor that is caused by the temperature, severe environment and the defect of work place, which is represented with \( W \).

Unsafe behavior of human beings refers to the human error that may cause the accident in power grid operation, which is represented with \( X \).

Unsafe condition of materials refers to the material condition that may cause the accident in power grid operation, which is represented with \( Y \).

Defective management refers to the deficiency of functions of management personnel that may cause
the accident in power grid operation, which is represented with Z.

3.2. Standardize Concepts Based on Set Theory

The relationship between concepts is obtained as follows through discriminating the difference between concepts by using the set theory from the perspective of the results caused by accident causation and the factors of accident accusation:

(1) It can obtain in accordance with the definitions of incident, accident, accident precursor and near-miss from the perspective of the results caused by accident causation:

\[ B \in A \]  \hspace{1cm} (1)  \\
\[ C \in A \]  \hspace{1cm} (2)  \\
\[ B_i \in B \]  \hspace{1cm} (3)  \\
\[ B_2 \in B \]  \hspace{1cm} (4)  \\
\[ B_1 \in B \]  \hspace{1cm} (5)  \\
\[ B_4 \in B \]  \hspace{1cm} (6)  

Since the near-miss is the special precursor, and one accident may be the precursor of the next accident, it can obtain:

\[ D \in C \]  \hspace{1cm} (7)  \\
\[ B \cap C \neq \emptyset \]  \hspace{1cm} (8)  \\
\[ B_i \cap C \neq \emptyset \]  \hspace{1cm} (9)  \\
\[ B_2 \cap C \neq \emptyset \]  \hspace{1cm} (10)  \\
\[ B_1 \cap C \neq \emptyset \]  \hspace{1cm} (11)  \\
\[ B_4 \cap C \neq \emptyset \]  \hspace{1cm} (12)  

Since the incident is divided into the accident and the near-miss, and the accident and the near-miss are mutually excluded, it can obtain:

\[ B \cup D = A \]  \hspace{1cm} (13)  \\
\[ B \cap D = \emptyset \]  \hspace{1cm} (14)  

(2) Similarly, from the perspective of accident causation factors, the risk is considered as the combination of the possibility of occurring the power grid accident and the severity of consequence, thus the risk is served as the universal set of accident causation factors. Meanwhile, by considering the theory of hazard of third kind and the definition of accident potential, it can obtain:

\[ E \in \Omega \]  \hspace{1cm} (15)  \\
\[ F \in E \]  \hspace{1cm} (16)  

It can obtain through the classification results of accident potential:

\[ X \in F \]  \hspace{1cm} (17)
\[(Y \in F) \quad \text{(18)}\]
\[(Z \in F) \quad \text{(19)}\]
\[(W \in F) \quad \text{(20)}\]

Therefore, we can obtain the Wayne diagram which describes the safety management concepts, as shown in Fig. 1.

4. Concept Identification Algorithm Flow

After the Wayne diagram of concept identification in safety risk management of power grid operation is obtained, in this chapter, an algorithm flow is required to help the identification for concepts after the accident in power grid operation or near-miss occurred in actual operation. Describe for judgment points:

(1) Judge whether there is difference \(\Delta\) between the normal power grid operation status and the actual result. There is a normal power grid operation status during the power grid operation, and when the actual power grid operation status is inconsistent with the normal status, it indicates that there is the difference \(\Delta\) between the actual status and the normal status. When there is no difference, it considers that the power grid is normally operated and there is no adverse incident. When there is difference, it considers that the power grid incident occurs and the next judgment shall be continued.

Figure 1. Venn diagram of conceptual discrimination.

(2) Judge the incident type. Since there is difference between the actual power grid operation status and the normal status which indicates that there is the power grid incident, it requires to judge whether the incident or the near miss occurred in accordance with the indicators such as supply reduction load of power grid and the number of power-off users.

(3) Judge the accident type. Since the accident occurred, it requires judging the accident type. The accident shall be divided by levels and classifications in accordance with the indicators such as supply reduction load of power grid and the number of power-off users.

(4) Judge whether the accident belongs to precursor.
It can be known from the definition of accident precursor that if an accident which has occurred fails to be intervened, with the passage of time, the other similar accident may be caused under the catalysis of deterioration factor. Therefore, when an accident occurs which fails to be immediately improved and causes the occurrence of the next similar accident, the accident can be considered as a precursor.

(5) Judge the hazard of first kind
Both the accident and the near miss are required to be investigated from the perspective of accident causation factors. The hazard of first kind refers to the energy materials or energy carriers which exist in the system and may accidentally release energy. In order to classify the causation factors in details, the first thing is to judge that the accident or the near miss is caused by which hazard of first kind.

(6) Judge the type of accident potential
After the hazard of first kind is obtained, it can classify the accident potentials in a more specific way in accordance with the different types of hazard potentials. Considering that there may be multiple accident potentials causing the accident or the near miss, this step is required to repeat for multiple times.

5. Conclusion
This paper firstly summarizes the basic concepts in safety risk management of power grid operation from the existing domestic and international standards, legal documents and literatures, and distinguishes the difference of concepts by using the set theory respectively from the perspective of the results caused by accident causation and the factors of accident causation, and form the conceptual extension model based on the form of Wayne diagram. Finally, an algorithm flow with the diagram form is used to help the identification for concepts after the accident occurred in actual operation.

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