A Construction Method of Power Grid Monitoring Knowledge Graph

Yi Liu¹, Xinjian Huang²*, Sen Li², Shang Gao³, Kun Ji², Huihui Li² and Hanyang Xu²

¹ State Grid Jiangsu Electric Power Company, Nanjing, Jiangsu, 210024, China
² Nari Research Institute, Nari Group Corp., Nanjing, Jiangsu, 211106, China
Email: huangxinjian001@163.com

Abstract. Centralized monitoring and integrated intelligent alarm functions have been implemented on the control system of smart power grid, which provides technical support for the judgment and disposal of power grid accident. However, there are still some problems such as lack of systematic analysis tools and cannot realize the correlation of alarms. This paper proposes a power grid accident analysis method based on monitoring information knowledge graph, which is constructed with power grid topology and historical alarm data rules. Using this method, the staff can accurately and quickly judge the power grid accident with the support of grid topology and alarm correlation, so as to improve the efficiency of power grid accident analysis and reliability of power grid control system.

1. Introduction
Power grid control system is an import tool of power grid company to control and ensure safe operation of power system. It can provide Real time, reliable and efficient support for the safe and stable operation of power grid [1-2].

The power grid control system has a very complex structure, which contains the hardware and software devices, model and data, et al. Therefore, the system still has some problems, including: (1) lack of association analysis of the monitoring information data. The power grid system operators have to deal with thousands even tens of thousands operation alarm information every day. This will greatly increase the work difficulty of operators, and will cause the failure identification untimely [3]. (2) lack of the experience and knowledge sharing tools. Nowadays, the failure handling experience are sharing by the typical failure report semi-annually or annually. The knowledge cannot be implemented online, causing the operator waste lots of time on repeatedly check, analyse and handle similar system malfunctions [4].

This paper proposes a power grid accident analysis method based on information knowledge graph. First, extracting entity, attribute, and relationship through power grid model and history alarm data, second, using the information graph to assist the operator to analyse alarm. The alarm analyzation is carried out by the power grid topology and data pattern. This method can achieve the experience and knowledge sharing, and improve the operation safety and stability of power grid control system.
2. Knowledge Graph

2.1. Origin of Knowledge Graph
The idea of using graph to indicate knowledge can trace back to 1956. In that year, Richens [5] put forward semantic network, it is based on semantics, and using interconnected nodes to form a network. In 1988, Stokman and Vries [6] put forward the idea of graph and the indication of structural knowledge. In 2012, Google officially put forward the concept of knowledge graph [7-8], it aims to extract entity, attribute and the association between entities from internet, then connect all kinds of information together to form a relation network.

2.2. Classification of Knowledge Graph
The knowledge graph can be divided into two categories: general knowledge graph and professional knowledge graph [9]. The professional knowledge graph has been widely used in smart grid applications, such as equipment maintenance, customer service, knowledge management centre, etc. [10] showed a professional knowledge graph built by state grid customer service centre, the knowledge graph is based on the knowledge extracted by the manual document, knowledge base and conversation data, and can provide support for the customer service. [11] proposed an equipment defects knowledge graph based on the corpus of equipment defect records, and it can be used for electric equipment defects searching.

3. Power Grid Accident Analysis

3.1. Monitoring Information Association
The status of devices with topological connection will affect each other when the power grid is in operations. Taking the common line trip accident as an example, Table 1 show the switch and protection signals alarm information of a transformer uploaded by the substation when line tripping happened. The alarm sequence shows that, the line protection exits and reclosing exit signals occurs reset action, along with the “switch off-on” alarm of line switch. The power grid accidents cannot be fully analysed only by observing the alarm sequence, but also combing the power grid topology and the historical law of alarm. However, the power grid topology and the historical alarm cannot be accessed easily by the existing power grid control system. The topology and the equipment connection have to be accessed from the connection drawing of substation. The historical law of alarm cannot be quickly searched yet. Therefore, building a monitoring information knowledge graph used for power grid accident analysis, can not only directly show the topological connection of equipment and protection signals, but also discovering the historical pattern of alarm.

| Time      | Alarm Content                                             |
|-----------|-----------------------------------------------------------|
| 01:30:52  | transformer, 117 switch spring not stored energy, action  |
| 01:30:52  | transformer, 117 overcurrent section II protection exit, action |
| 01:30:52  | transformer, 117 switch control circuit disconnecting, action |
| 01:30:52  | transformer, 117 switch spring not stored energy, action  |
| 01:30:53  | transformer, 117 overcurrent section II protection exit, action |
| 01:30:53  | transformer, 117 switch control circuit disconnected, action |
| 01:30:53  | transformer, 117 switch control circuit disconnected, action |
| 01:30:53  | transformer, 117 protections exit, action                 |
| 01:30:53  | transformer, 10 kV. Line 1 117 switch, switch off       |
4. Monitoring Information Knowledge Graph

4.1. Overall Design of Monitoring Information Knowledge Graph

Figure 1 shows that, the entities of substation monitoring information knowledge graph include: substation entity, bay entity, equipment entity, protection signal entity. Equipment entity includes AC line entity, transformer entity, bus entity, circuit breaker entity, etc. Protection signal entity includes main transformer differential action, circuit overcurrent protection and some other protection signals.

![Figure 1. Substation knowledge map design.](image)

4.2. Extracting Entities, Attributes and Correlation from Power Grid Model

Tables 2 to 5 are the tables in the relational database, the constructing process of the entities and relationships in the knowledge graph based on these four tables are as followed:

Table 2 contains one record, which can be extracted as a substation entity. The name attribute of the entity is "transformer". The field ID, voltage level and substation type in the table are all the attributes of the substation entity. The records in table 3 can be extracted into three bay entities, and the "substation ID" field is associated with the substation table by foreign key. The transformer body "No.1 main transformer" is extracted from the table 4, and the subordinate relationship between the main transformer and the substation is constructed through the foreign key association of the "substation ID" field. The transformer winding entities are extracted from table 5. The field "Bay ID" has a foreign key association with the bay table, which can construct the subordinate relationship between the transformer winding and the corresponding bay entity.

**Table 2. Substation Table.**

| ID    | Name       | Voltage Level | Substation Type |
|-------|------------|---------------|-----------------|
| 687750| transformer| 220 KV        | substation      |

**Table 3. Bay Table.**

| ID    | Name                     | Substation ID | Voltage Level |
|-------|--------------------------|---------------|---------------|
| 259933| transformer/ 10kV.1 main transformer low voltage bay | 687750       | 10 kV         |
| 259932| transformer/ 110kV.1 main transformer low voltage bay | 687750       | 110 kV        |
| 401297| transformer/ 220kV.1 main transformer | 687750       | 220 kV        |
| ID   | Name                           | Substation ID | Transformer type | Winding type |
|------|--------------------------------|---------------|------------------|--------------|
| 687750 | transformer/ No.1 main transformer | 220 KV        | substation       | Three winding |

**Table 4. Transformer Table.**

| ID   | Name                           | Bay ID         | Transformer type | Voltage Level | Winding type |
|------|--------------------------------|----------------|------------------|---------------|--------------|
| 219981 | transformer/ 10kV.1 main transformer-low | 259933     | 505942            | 10kV          | low          |
| 219982 | transformer/ 10kV.1 main transformer-medium | 259932      | 505942            | 110kV         | medium       |
| 219980 | transformer/ 10kV.1 main transformer-high | 401297      | 505942            | 220kV         | High         |

**Table 5. Transformer Winding Table.**

The knowledge graph of a transformer constructed from table 2 to table 5 is shown in figure 2. The entities include: substation entity, bay entity, main transformer entity and main transformer winding entity. The subordinate relationship between bay entity and substation entity, the main transformer entity and substation entity.

![Knowledge Graph](image)

**Figure 2.** The building steps of knowledge graph.

4.3. **Extracting Connection Relationship from Connection Node Number**

Figure 3 shows that, the connection relationship between entities can be established according to the connection node number in the entity, so as to connect different devices. Connection relation is the mapping of power grid topology in knowledge graph.
4.4. Extracting Co-occurrence Relationship from History Alarm Data

The co-occurrence relationship between monitoring information is extracted by calculating the conditional probability. Suppose that the historical alarm data is divided into N different sections, among the N sections, there are $C_1$ sections contains the alarm of monitoring information $S_1$, and there are $C_2$ sections contains the alarm of monitoring information $S_2$. There are $D$ sections contains the alarm of both $S_1$ and $S_2$. According to the formula of conditional probability, make conditional probability $P(S_1|S_2)$ representing the co-occurrence relationship from $S_1$ to $S_2$, the conditional probability $P(S_2|S_1)$ representing the co-occurrence relationship from $S_2$ to $S_1$, the formula is as follows.

\[
P(S_1|S_2) = \frac{P(S_1 \cap S_2)}{P(S_2)} = \frac{\frac{D}{N} \cdot \frac{C_1}{C_2}}{D} = \frac{D}{N} \cdot \frac{C_1}{C_2} \tag{1}
\]

\[
P(S_2|S_1) = \frac{P(S_1 \cap S_2)}{P(S_1)} = \frac{\frac{D}{N} \cdot \frac{C_1}{C_2}}{\frac{D}{N} \cdot \frac{C_1}{C}} = \frac{D}{N} \cdot \frac{C_1}{C_2} \tag{2}
\]

5. Case Analysis

Taking the line trip accident of transformer in Section 2.2 as an example, the method of power grid event analysis based on monitoring information knowledge graph is described in detail. Marking the alarm node in the knowledge graph according to the alarm sequence, the result is shown in figure 4. The alarm of the protection signal node marked as blue is common in the line trip accident, and all are in the same bay or public bay. The monitor can judge that it is the protection signal alarm related to the "line 112 switch" signal alarm based on experience. The alarm time interval between "section I bus grounding" and "line 1 112 switch" is 1s, which belongs to different bays. Additional information is needed to judge whether they are related and whether they belong to the same event.

Figure 4 shows that the "bus section I grounding" node belongs to the "bus section I" node, and there is a bidirectional connection between the "Line 1 112 switch" node and the "bus section I" node; In addition, there is a high co-occurrence relationship between "line 1 112 switch" node and "section I bus grounding" node. According to the above two information, we can conclude that the "section I bus grounding" alarm also belongs to the accident trip event, which can be incorporated into the event.
Figure 4. The knowledge graph of a transformer.

The above case analysis shows that mapping alarms to the knowledge graph can more easily obtain the association relationship and data rules between nodes, so as to speed up the process of event analysis and improve the efficiency of judgment.

6. Conclusion
This paper is aimed at the application of event analysis of power grid, and uses knowledge graph construction technology and big data analysis technology to provide knowledge and data support for power grid alarm analysis, and improve the efficiency and accuracy of accident judgment. The main achievements are as follows:

(1) Facing the analysis of power grid accidents, the substation entities, bay entities and equipment entities related to business are extracted from the grid model and historical alarm data by using big data technology. The subordinate, connected and co-occurrence relationships are extracted, the attributes of entities and relationships are extracted, and the knowledge map of monitoring information is constructed to realize knowledge and experience sharing and reuse.

(2) The relationship provided by the monitoring information knowledge graph is used to assist the monitors to analyse the alarm, quickly judge whether there is correlation relationship between alarms and whether there is alarm leakage, and comprehensively judge the power grid accidents more accurately and improve the work efficiency.

In practice, the following limitations are found: 1) when the power grid model changes frequently, the knowledge graph of monitoring information needs to be changed accordingly. Whether the current grid topology can be correctly reflected is the prerequisite for correct judgment of accidents; 2) For some accidents, the historical alarm records are scarce, and the statistical data rules may be biased, which will affect the analysis and judgment. In the future, this paper will study the local changes of knowledge map and accident sample generation, and further improve the practical effect of the analysis method.

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