Substation operation ticket system based on natural language analysis and intelligent reasoning

Chen Ming, Chen Dekai*, Jiang Yupeng

(Kunming Power Supply Bureau of Yunnan Power Grid Corporation, Kunming, Yunnan, 650011, China)

*Corresponding author’s e-mail: chendekai@im.yn.csg

Abstract: [Background/Reason] The operation ticket system is an important measure to ensure the safety of substation operation. At present, the issuance and review of substation operation tickets rely on manual operation knowledge and experience, and there are problems such as low work efficiency, lack of standardization, and human error. The risk of grid operation is reduced. [Method/Process] This paper proposes a substation operation ticket system based on natural language analysis and intelligent reasoning. It uses typical/standard operation tickets as the basic corpus and builds a natural language analysis model based on manual labeling to achieve compliance with the operation tickets. Sexual inspection, deduction and comparison of equipment status. Finally, combining the primary wiring diagram of the substation and the operation ticket to construct the equipment relationship knowledge map and the equipment operation knowledge map, use the Neo4j graph database for storage, and realize the intelligent drafting of operation tickets based on the graph search method. [Results/Conclusions] The research results have been implemented and applied in three substations in a certain area, verifying that the system has a high degree of intelligence and versatility, and can effectively solve the existing problems of standard invoicing and audit errors, and improve operation The work efficiency of personnel and the safety control level of power grid substation operation..

1. Introduction
During the operation of the power system, frequent operation mode changes and periodic maintenance and repair work are required. The correctness of equipment operation is the basis for ensuring the safe and stable operation of the power system [1]. With the expansion of the scale of the power grid, the continuous change of new equipment and new technology, the complicated operation of power grid transformation has brought huge challenges to the safe production of the power grid. The operation ticket system is an important basis for performing power grid transformation operations. The operation of power grid transformation involves a large number of operation ticket issuance and review operations every day, which requires a large workload and low work efficiency. The correctness and reliability of substation operation ticket compilation depend on operating knowledge and work experience, which are prone to errors and increase grid operation risks.

In order to improve the informatization level of power grid substation operation management, various power companies and operation departments develop substation operation ticket management systems, and use database storage technology to store historical and typical operation ticket data in the system. During the invoicing process, operators pass the key. The task name or key equipment name retrieves the relevant operation ticket, modifies part of the core data and saves it to generate a new operation ticket, and then the operation ticket becomes effective after being reviewed by the audit department [6-8]. This method is still in the manual stage, with low degree of automation and intelligence, and cannot adapt to the current transformation needs of the power grid.

Therefore, in view of the lack of intelligent anti-error checking and automatic ticket drafting functions in the current substation operation ticket system, this article deeply studies artificial intelligence related technologies, and designs and implements a substation operation ticket based on natural language analysis

---

Creative Commons Attribution 3.0 licence. Any further distribution of this work must maintain attribution to the author(s) and the title of the work, journal citation and DOI. Published under licence by IOP Publishing Ltd
and intelligent reasoning. The system comprehensively improves the accuracy and standardization of operation ticket issuance, avoids grid operation risks caused by audit errors, and improves the safety management and control level of grid transformation operations.

2. Research status of power grid substation operation ticket system

Since the birth of the operating ticket system, it has roughly experienced three stages: computer-assisted invoicing, graphical check invoicing, and expert system inference invoicing [11]. The computer-aided invoicing system is the most widely used in all levels of power transformation and plant and station, and is currently the most common operation ticket management system. The graphic check and billing system simulates plant and station lines and equipment wiring diagrams, simulates equipment operations based on a graphical method, and combines five-prevention equipment operation rules to verify and generate operation items. Due to different factors such as the wiring methods and equipment types of each plant, this type of system has poor migration ability and cannot be used universally [9-10]. The expert system reasoning operation ticket system is developed based on artificial intelligence technology. It builds a knowledge base by solidifying the relevant operating knowledge and the working experience of the operators, and generates operation tickets through knowledge search and reasoning [11]. With the continuous maturity of artificial intelligence technology in recent years, many researchers have carried out technical and application model innovations around the expert operation ticket system, and achieved a series of research results.

Literature [2] proposed an intelligent operation ticket generation method based on rule-based reasoning. By constructing a five-prevention operation rule library, analyzing SSD files to obtain equipment status, and combining equipment status reasoning and equipment operation rules to realize automatic ticketing. Literature [3] proposed an automatic ticket issuance method based on Rete algorithm reasoning. The operation atomic task is obtained by searching the shortest rule path, and finally the complete operation task is synthesized by each atomic task in order. Literature [4] proposed a general method for generating operation ticket tasks based on five-element task templates of terminal information, equipment interval, status and connection relationship. Literature [5] proposed a method of using natural language processing technology to analyze maintenance work application tickets, combined with a substation operation expert system to automatically reason to generate substation instructions. This paper draws on the related research results of literature [4], and on this basis, proposes the use of knowledge graph technology to solve the problems of existing expert systems relying on manual construction and manual maintenance [12], constructing the knowledge base in a semi-automatic way, and Use graph data technology for knowledge storage to improve knowledge query efficiency.

3. Design plan

This paper designs a substation operation ticket system based on natural language analysis and intelligent reasoning. By obtaining typical tickets and archived ticket data sets, building a natural language analysis model and operation ticket knowledge graph model to realize operation ticket compliance inspection and equipment status deduction ratio and operation ticket intelligent drafting. Operation ticket compliance inspection: use natural language analysis model to identify and analyze the operation ticket content, compare the standard ticket library, and check whether the operation ticket has missing items, inverted items, skipped items, added items, and standard terminology issues. Equipment status deduction and comparison: Obtain real-time status data of substation operating equipment, use natural language analysis models to extract operating equipment and operating actions of operating items, infer the status of equipment after the equipment operation is completed based on the operating actions, and compare it with the actual status. Realize equipment status review. Intelligent drafting of operation tickets: Combining the primary wiring diagram of the substation to construct a knowledge graph of equipment relations, abstract each operation item in the standard ticket library, construct an operation knowledge graph, use Neo4j graph database to store the knowledge graph, and search based on knowledge And knowledge reasoning realizes the intelligent drafting of operation tickets. The overall design architecture of the system is shown in Figure 1:
4. System key technology

4.1 Intelligent check technology of operation ticket based on natural language analysis

Use natural language analysis and machine learning technology to extract the content of the operation ticket \(^{[13]}\). First, sort out the typical ticket and standard ticket data set, define 14 types of tags, see Table 1, and build a part-of-speech tagging model based on manual tagging. Then use the Pre-training of Deep Bidirectional Transformers for Language Understanding (BERT) model to segment the operation ticket corpus, and input the word segmentation result into the part-of-speech tagging model to obtain the part-of-speech tagging result of the operation sentence. According to the predefined standard lexicon grammar rules, Feature words such as lines, equipment, operation actions, and proprietary names in the operation ticket are extracted. Finally, combining the word segmentation result of the BERT model and the part-of-speech tagging state sequence, the operation item sentence is abstracted into a standard syntax representation, and the operation ticket semantic analysis model is constructed, and the compliance check of the operation ticket content is realized through the semantic similarity calculation.

Table 1 Operation ticket label definition

| Label symbol | Label category | Example |
|--------------|----------------|---------|
| ns           | line           | 10kV City Stadium Line |
| nr1          | Primary equipment | Circuit breaker, isolating switch |
| nr2          | Secondary equipment | 10kV backup automatic switch and line protection measurement and control screen |
| nr1s         | Sub-device 1    | Motor energy storage air switch |
| nr2s         | Sub-device 2    | 410 control switch for station 1 |
| mr1          | Primary equipment number | 410, 1011 |
| mr2          | Secondary equipment number | 1LP23, 1QK |
| nz           | Proper nouns    | Voltage indication, overload |
| v            | Operational verb | Pull to, exit, disconnect |
| ad           | State word      | On, off, overhaul position |
The operation ticket segmentation model and the part-of-speech tagging model belong to the sequence tagging task of natural language processing NLP. It treats a single Chinese character as an element in a linear sequence by using Chinese text as a one-dimensional linear input sequence, and gives each of the linear sequences Labeling an element with a certain label in the label set is essentially a problem of classifying each element in a linear sequence according to the context. In the BERT model, the model is pre-trained through the two tasks of "Fill in the blank task" and "Next sentence prediction". In the sequence labeling process of Chinese text, the first token of each sequence is embedded as a special classification, and the rest The remaining tokens represent a single Chinese character. The input of the BERT model is composed of word (character) vector, sentence category and word (character) position information, and its output is a collection of all parts of speech of Chinese text. For Chinese text, the minimum input unit of the BERT model is a single Chinese character, and the part-of-speech information needs to be labeled with words. Therefore, before using the BERT model to train the corpus, data preprocessing is required, that is, the original text is split into a series of Chinese characters. The part of speech tagging for each Chinese character mainly adopts the "BIO" word segmentation processing method, where "B" represents the beginning character, "I" represents the middle character, and "O" will not appear in part of speech tagging tasks. It is mainly used for naming entities Marking the task. For an operation ticket sentence, the word segmentation and part-of-speech tagging results are shown in Table 2:

Table 2 Example of part-of-speech tagging results of operation ticket content based on BERT model

| d | Of, will |
|---|---|
| c | conjunction |
| P | preposition |
| f | Position of the word |
|  | Closing side, line side, side near main transformer |

The operation line protection measurement and control screen (IV) 10kV.10kV thyristor line 080 circuit breaker remote/local position switch from the "local" position on the opening side to the "remote" position

| B_d | B_nr2 | I_nr2 | I_nr2 | I_nr2 | I_nr2 | I_nr2 | I_nr2 | I_nr2 | I_nr2 |
|-----|-------|-------|-------|-------|-------|-------|-------|-------|-------|
| I_nr2 | I_nr2 | I_nr2 | I_nr2 | I_nr2 | I_n2s | I_n2s | I_n2s | I_n2s | I_n2s |
| I_nr2 | I_nr2 | I_nr2 | I_nr2 | I_nr2 | I_n2s | I_n2s | I_n2s | I_n2s | I_n2s |
| I_nr2 | I_nr2 | I_nr2 | I_nr2 | I_nr2 | I_n2s | I_n2s | I_n2s | I_n2s | I_n2s |
| B_f | I_f | I_f | B_ad | I_ad | I_ad | I_ad | I_ad | I_ad | B_v |
| I_v | I_v | B_ad | I_ad | I_ad | I_ad | I_ad | I_ad | I_ad | I_ad |

4.2 Operation ticket status deduction and comparison technology

Use the natural language analysis model to tag the operation items of the operation ticket, and retrieve the last operation device and operation verb in each sentence backward. Among them, operational verbs are divided into two categories, one is state verbs, such as: disconnect, open, close, take off, put in, withdraw, insert, pull out, etc., and the other are directional verbs, such as: Shake to, switch to, pull to, push to, display, etc., for directional verbs, search the last state word backwards. "Disconnect 10kV City Gymnasium Line 080 Circuit Breaker" can deduce the equipment state sequence as {10kV City Gymnasium Line 080 Circuit Breaker: Disconnected}, "10kV City Gymnasium Line 080 Circuit Breaker Remote/Local Position Switch from the Opening Side" Switching from "on-site" position to "remote" position" can deduce the equipment state sequence as {10kV city gym line 080 circuit breaker remote/local position switch: "remote" position}, compare the equipment deduction sequence with the actual equipment state sequence Yes, check whether the operation result is consistent with the operation instruction ticket.

4.3 Intelligent ticketing technology of operation ticket based on knowledge graph reasoning

By analyzing the primary wiring diagram of the substation, a section of the busbar is abstracted as a node, the direct equipment main transformers and circuit breakers connected to the busbar are directly connected to the busbar, and the busbar branches are abstracted into branch nodes (using I, II, III, etc.) The device connected on the busbar branch is connected to the branch node as an indirect device of the busbar to
construct a knowledge map of the equipment relationship of the substation. The knowledge map of the equipment relationship is shown in Figure 2.

![Knowledge graph of device relationship](image)

**Figure 2 Knowledge graph of device relationship**

Through sorting out the operating task categories involved in substation operations, and labeling them, as shown in Table 3. The equipment operation status of each type of operation task is abstracted as a node. The beginning and end nodes represent the initial and end states of equipment operation. The connected nodes in the middle constitute a path. The content of the nodes on the path specifically represents each operation step to construct a knowledge graph of equipment operation. For the operation task "turn 10kV mound village line 084 circuit breaker from running to cold standby" corresponding to the operation task category "DA", the operation steps under this operation task are abstracted as follows:

- **Step 1**: Check (*) the circuit breaker live display device shows power
- **Step 2**: Open (*) the circuit breaker
- **Step 3**: Check (*) the circuit breaker position indication and current indication are correct
- **Step 4**: Check (*) the circuit breaker is in the open position
- **Step 5**: Switch (*) the line protection measurement and control screen (*) the circuit breaker control switch from the "remote control" position to the "local" position on the trip side
- **Step 6**: Open (*) the line side (*) isolating switch
- **Step 7**: Check (*) the line side (*) isolating switch is in the open position
- **Step 8**: Roll the (*) handcart from the working position to the test position
- **Step 9**: Check (*) the handcart has been rolled to the test position

The abstract operation steps are represented by a knowledge graph, as shown in Figure 3.
Table 3 Example of labeling of operational tasks

| Operation task category                      | symbol | Operation task category                      | symbol |
|----------------------------------------------|--------|----------------------------------------------|--------|
| Cold standby transfer                        | AB     | Exit the whole station remote control function | ZI     |
| Overhaul to cold standby                     | BA     | XXX interval related remote control function is put into use | YK     |
| Cold standby to hot standby                  | AC     | Exit XXX interval related remote control function | KY     |
| Hot standby to cold standby                  | CA     | Exit low frequency and low voltage load shedding protection | IZ     |
| Cold standby transfer                        | AD     | Low frequency and low voltage load shedding protection input | ZI     |
| Running to cold standby                      | DA     | Backup power supply automatic switch protection input | JZ     |
| Hot standby transfer                         | CD     | Exit the backup power automatic switch protection | ZJ     |
| Running to hot standby                       | DC     | Main variable cost gas protection input | KZ     |
| Exit reclosing                               | EF     | Exit the main variable weight gas protection | ZK     |
| Put into reclosing                           | FE     | Main transformer protection investment | KR     |
| Circuit breaker protection input             | GZ     | Charge module input | TR     |
| Exit circuit breaker protection              | ZG     | Exit the charging module | RT     |
| Full station remote control function input   | JZ     |                                              |        |

Figure 3 Operational knowledge graph

The Neo4j graph database is used to store the equipment relationship knowledge graph and the operation knowledge graph [14], each entity is identified by a unique id code, branch identifies the device line name, equipment identifies the device name, number identifies the device number, and total_name identifies the direct parent device and Device name, type identifies the type of operation task. Use graph database to query operation tasks to realize intelligent drafting of operation tickets. The operation task query statement is as follows:
query('match p=((:state)-[xx*]-(:statue)) return p')

5. Conclusion
The substation operation ticket system based on natural language analysis and intelligent reasoning proposed in this paper is based on 3,759 operation tickets and 32,600 operation steps of three substations in a certain area for basic data sorting and data labeling, and according to 80%, 10%, and 10% Divide the training data set, test data set and verification data set according to the ratio of, train the operation ticket content AI analysis model, realize the compliance check of the operation ticket content, and realize the operation ticket intelligent drafting based on the knowledge graph construction technology and the graph database storage technology. The system was implemented and applied in three substations in the area, which greatly improved the accuracy and efficiency of operation ticket issuance and review. The application showed that the system can be used for flexible migration and application in other substations, with a high degree of generalization [15], it can better solve the series of problems that rely on manual operation ticket issuance and review in the power system, and improve the level of power grid safety management.

Acknowledgment
The project was financially supported by the research on Research on AI analysis technology of substation operation ticket content based on natural language processing technology (No.YNKJXM20180459)

References
[1] Wang Chaojie. Design and research of intelligent auxiliary decision-making system for power grid dispatching operation orders [D]. North China Electric Power University, 2016.
[2] Tan Jing, Xia Tong, Dou Haoxiang, Zheng Mingzhou. Rule-based reasoning-based intelligent substation operation ticket automatic generation method[J]. Power System and Clean Energy, 2019, 35(07): 55-65.
[3] Zeng Li, Meng Wen. Automatic generation system of power grid operation ticket based on expert system [J]. Electrical Automation, 2017, 39(01): 64-65+69.
[4] Zhang Dongying, Yang Junwei, Huang Jianyang, Wang Wei. General method for automatic generation of operation ticket tasks[J]. Automation of Electric Power Systems, 2018, 42(24): 169-175.
[5] Li Zhi, Zhang Zhen, Zhang Ye, Yin Tianhua. Research and application of intelligent dispatch operation ticket system based on natural language analysis and expert system [J]. Hebei Electric Power Technology, 2019, 38(06): 44-47.
[6] Hao Fangzhou, Luo Linhuan, Sun Qizhen. Research and application of intelligent operation ticket generation method in distribution network[J]. Wireless Internet Technology, 2019, 16(17): 123-124.
[7] Lu Chengyu, Luo Huafeng, Ding Feng, Liu Junhong, Bao Wei. Research on the content extraction technology of smart station operation ticket based on hidden Markov model[J]. Energy Engineering, 2019(02): 23-27.
[8] Wang Zehui. Research on Intelligent Invoicing Method Based on Expert System[D]. North China Electric Power University, 2019.
[9] Yu Haiyang. Development of intelligent operation ticket system for grid dispatching[D]. Northeast Petroleum University, 2018.
[10] Xu Jiayan, Song Fuhai, Lu Zhen. Visualization of secondary maintenance measures for smart stations and design and implementation of one-key operating system [J]. Power System Protection and Control, 2017, 45(16): 136-144.
[11] Feng Li. Constructing a knowledge map of Chinese poetry in middle school based on Neo4j database [D]. Shaanxi Normal University, 2019.
[12] Huang Shuang, Zheng Han, Dou Zhuang, Ao Bang. Application of intelligent error prevention technology for power grid dispatching operation [J]. Integrated Circuit Applications, 2020, 37(06): 94-95.
[13] Pan Jiafeng, Zhu Hejian, Gao Jie, Lin Zhongsen, Lin Jiang, Cai Huihui. Research and application of
anti-misoperation platform in intelligent operation ticket system[J]. Power System Protection and Control, 2018, 46(20):158-163.
[14] Li Qunshan, Li Guotong, Lai Hongyi, Su Renbin. Research and application of an integrated intelligent operation ticket system based on state order operation mode [J]. Smart Grid, 2017, 5(02): 207-213.
[15] Dong Kaihe. Summary of knowledge expression methods based on the topology operation order expert system of intelligent substations[J]. Chemical Management, 2015(30): 46.