IOP Conference Series: Materials Science and Engineering

PAPER • OPEN ACCESS

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To cite this article: Ding Jun *et al* 2018 *IOP Conf. Ser.: Mater. Sci. Eng.* **366** 012068

IOP Conf. Series: Materials Science and Engineering **366** (2018) 012068 doi:10.1088/1757-899X/366/1/012068

Research on Safety Assessment for Power Line Design

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Abstract. As the source of power line project, line design is a key part of life cycle management. The safety and reliability of line design can provide necessary support for construction, operation and maintenance. This paper proposes a risk-based approach for safety management in line design, decomposing risks into two dimensions, the probability and the consequence. Based on factors, such as risk assessment, number of historical incidents, consequence of historical incidents, qualification of proofreading and auditing, this approach in line design can predict risk status in real time, provide scientific basis for risk control, and minimize safety hazards.

1. Introduction

With the transformation of economic structure, China has vigorously promoted the construction of smart cities in recent years, putting forward higher requirements for grid construction in cities [1]. As the source part of grid project, line design is related to the whole process quality control, including construction, operation and maintenance [2-3]. Therefore, improving the safety management of line design can reduce safety hazards and ensure the stable operation of the grid.

2. Key point of power line design [4-8]

Route selection is the primary element considered in power line design [9]. Besides municipal planning and field environment, it also needs to take the following factors into account, safety distance, tower form, foundation form, cable channel form, overall investment, transportation convenience, and construction influence on surrounding facilities.

Based on the long-term grid planning, type design of the wire and cable must comprehensively consider the current density and transmission capacity in the line, as well as mechanical strength calculated, natural conditions and geographical environment along the route [10-11].

The tower and corresponding foundation are the core parts of overhead line projects, both cost accounts for about 40% of the total project investment. The design of the tower, the foundation and the insulator must take the followings into account, voltage grade, load size, mechanical strength, filth intensity and geological conditions [10-11].

Cable channel is the core of cable line project, which accounts for about 45% of total investment. At present in south area of China, the laying of cables is mainly the combination of cable trench and cable duct [12]. Channel design is affected by voltage grade, route path, cable quantity, mechanical strength, and geological condition.

3. Quantitative evaluation of risks for power line design

During the line design cycle, we need to take risks into account, such as tower risk, wire risk, foundation risk, insulator risk, cable risk, channel risk, investment risk and environment risk [13]. These factors are not only related to the whole life cycle of the line, but also closely related to the safe operation of the grid and the comprehensive development of the city. Therefore, during design process, relevant designers should consider the possible consequence of these risks and strive to minimize the occurrence probability and potential consequence of these risks.

According to the two-dimensional evaluation theory, risks can be decomposed into two dimensions, the occurrence probability and the potential consequence [14]. Referring to classification standards for incidents in "Investigation procedures for safety incidents of State Grid", we carry out risk's quantitative evaluation based on three probability rankings and eight consequence rankings [15]. The evaluation matrix is shown as table 1. Larger number means higher probability and worse consequence.

In this paper, all incidents mentioned are caused by corresponding design risks.

Table 1. Evaluation matrix for probability and consequence.

Probability	Consequence							
	1	2	3	4	5	6	7	8
3								
2								
1								

4. Quantitative evaluation of risks for power line design

We must correctly deal with risks in line design, trying to find out it's regularity and rationality, to explore the balance among investment control, environment protection and safety control, and finally to realize the optimization of line design. Hence, we need to carry out quantitative control at different levels, based on the probability and consequence of risks [16-21].

According to the existing risks and previous incidents of line design in an area, based on incidents' frequency, risks' potential consequence and weight factors, the real-time probability and consequence of risks is calculated. Thus, risk control can be targeted. This paper takes cable risk as an example to show the detailed calculation procedure.

4.1 Average calculation of the probability value and consequence value for existing risks by assessments.

We evaluate each cable risk to get its residual probability and residual consequence. In other words, the probability and consequence of current cable risk is calculated by numeric values, and the result is rounded, calculation process is shown below.

- $L_{av}=(\Sigma\ L_{pi})/n$, L_{av} is the average probability, L_{pi} is the probability of the single assessment, and n is the quantity of all assessments.
- $C_{av}=(\Sigma\ C_{pi})/n$, C_{av} is the average consequence, C_{pi} is the consequence the single assessment, and n is the quantity of all assessments.

Table 2. Average calculation for cable risk by assessment.

Assessment	Assessment Probability	Assessment Consequence
Ass. 1	3	2
Ass. 2	1	1

Ass. 3	1	3
Ass. 4	1	1
Average	1.5(round to 2)	1.75(round to 2)

In table 2, the calculation shows that the average probability of the cable risk is 2, and the average consequence is 2.

4.2 Adjustment of this average value to make sure it reflects actual incidents' consequences over the last 12 months.

We evaluate all cable incidents (in last 12 months) and find out the actual consequence of each incident based on the evaluation matrix. If the highest actual consequence over the last 12 months is higher than the average consequence calculated in step 1, the average consequence automatically jumps up to reflect the highest one.

As shown in table 3, 6 cable incidents occurred in last 12 months and the highest consequence value is 3. Compared with the highest value, average consequence jumps up to 3.

Table 3. Consequence of actual cable incidents.

Cable Incident	Actual Consequence
Incident 1	1
Incident 2	3
Incident 3	1
Incident 4	1
Incident 5	2
Incident 6	1

Hence, probability of the cable risk remains 2, and the consequence is 3 in step 2.

4.3 Calculation of severity index based on statistical analysis on all incidents

The actual incidents over the last 12 months are classified in table 4 (the horizontal axis is the incident type, and the vertical axis is the potential consequence level).

Table 4. Statistics of all actual incidents (in last 12 months)

Realistic Consequence	Incident Type (corresponding to risks)								
	Cable	Cable channel	Tower	Foundation	Insulator	Wire	Investment	Environment	Total
8	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0	0
5	0	1	0	0	0	0	1	0	2
4	0	1	0	0	0	0	1	0	2
3	1	2	0	1	0	0	2	0	6
2	2	1	1	2	2	1	3	0	12
1	3	2	2	5	2	1	4	1	20

In the same consequence ranking, incident frequency is calculated while the quantity of cable incidents is divided by all incidents quantity. The severity index in each ranking is calculated by the multiplication of incident frequency and weight factor, as shown in table 5 [18].

IOP Conf. Series: Materials Science and Engineering **366** (2018) 012068 doi:10.1088/1757-899X/366/1/012068

Table 5. Calculation of severity index for cable incidents

Realistic Consequence	Cable Incident Quantity	Total Quantity	Incident frequency		Weight Factor	Calculation	Severity Index
8	0	0			64		
7	0	0			49		
6	0	0			36		
5	0	2	0/2	0	25	0 * 25	0
4	0	2	0/2	0	16	0 * 16	0
3	1	6	1/6	0.1667	9	0.1667 * 9	1.5003
2	2	12	2/12	0.1667	4	0.1667* 4	0.6668
1	3	20	3/20	0.1500	1	0.1500 * 1	0.1500
						Total	2.3171

Severity threshold is defined as 50% of the top incident index among all incidents. If severity index of one risk is equal or larger than the threshold, the probability and consequence of this risk will have an increase of one ranking, as shown below.

- Severity index of the risk$\geqslant$ Severity threshold

Table 6. Severity index of all risks.

Risk Type	Severity Index
Cable	2.3171
Channel	23.9333
Tower	0.4333
Foundation	2.4167
Insulator	0.7667
Wire	0.3833
Investment	24.7000
Environment	0.0500

We get the severity threshold, 12.35, from table 6. Thus, the probability and consequence of cable risk remains unchanged.

4.4 Calculation of nonconformity index for proofreading and auditing

The nonconformity index is the quantity of nonconformity for proofreading and auditing in all line design projects over the last 12 months, classified by risk types. The nonconformity threshold is defined as 50% of the top nonconformity index.

The probability of the risk will have an increase of one ranking by the following two conditions.

- Nonconformity index of the risk$\geqslant$ Nonconformity threshold
- Nonconformity index of the risk$\geqslant$ 40

As shown in table 7, nonconformity index of cable risk is 69, meeting the above two conditions. Thus, the probability of cable risk increases from ranking 2 to ranking 3.

Table 7. Severity index of all risks.

Risk Type	Nonconformity Index for Proofreading and Auditing
Cable	69
Channel	122
Tower	57
Foundation	82
Insulator	45
Wire	29
Investment	96
Environment	15

Finally, the probability and consequence of cable risk is revised from (2,2) to (3,3).

5. Conclusion

Safety management of line design is the source part of life cycle management. The quantification of risks based on the probability and consequence can effectively improve the source prevention of safety management, timely evaluate possible design flaws and improve designers' ability. In addition, it can also help the construction, operation and maintenance departments to carry out hazard management to ensure the safe and stable operation of the grid.

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