Risk Analysis for Evolution of Transmission Lines Tripping Fault Induced by Wildfires located in Xiangxi, China

Changkun Chen¹,², *, Tong Xu², a, Dongyue Zhao², b and Peng Lei², c

¹State Grid Hunan Elect Power Corp, Disaster Prevent & Reduct Ctr, State Key Lab Disaster Prevent & Reduct Power Gri, Changsha 410007, Hunan, Peoples R China
²Institute of Disaster Prevention Science and Safety Technology, Central South University, Changsha 410075, P. R. China
*Corresponding author e-mail: cckchen@csu.edu.cn, a tongxuxut@csu.edu.cn, b dongyue@csu.edu.cn, c leipeng2015@csu.edu.cn

Abstract. The serious consequences of transmission lines tripping fault induced by wildfires (TLTFIW) urges scholars to pay more attention to the safe operation of transmission lines. To illustrate the evolution process of TLTFIW and quantitatively evaluate the occurrence probability of subsequent events, an algorithm used for TLTFIW is proposed by using ETA, FTA and fuzzy number theory in this paper. The evolution process of TLTFIW is simulated according to ETA, which is divided into six stage including wildfires occurring, early wildfires early-monitoring, Wildfires extinguishing, Wildfires spreading, transmission lines tripping, and re-closing failure. In addition, the reason of the subsequent events in the evolution process are analysed by FTA, and the trapezoidal fuzzy theory is employed to calculate the probability of each events. Finally, based on the evaluation results, suggestions are provided for the evolution links with greater risks. Furthermore, transmission lines located in Xiangxi is introduced to present an application of the algorithm.

1. Introduction
In recent years, the demand for transmission lines of the country has increased with the rapid development of the national economy [1]. However, long-distance transmission lines often cross the mountainous terrain [2], which is extremely vulnerable to various natural and climatic disasters. Taking Hubei Province, China as an example, there were more than 30 tripping accidents caused by wildfires in 2013, resulting in the economic loss of more than 1.5 million US dollars [3]. These accidents may lead to a large-scale blackout, which will seriously affect the normal life of the residents and cause an enormous economic cost [4].

Widespread attention is attached to the risk research of transmission lines, especially the related model of TLTFIW. Based on the risk analysis of wildfires to transmission lines and the probability of transmission lines tripping, Shi et al [5] established a new model to assess the tripping risk of high-voltage transmission lines. Ansari, B et al [6] mainly constructed a model which can simulate the impact of wildfires on different line grade. In addition, the influence of wind on the tripping of transmission lines is emphasized, including the relationship between wind speed and power interruption [7], and the convective heat transfer cooling effect of wind on transmission lines [8]. Regarding the prevention of
transmission lines fault, Liu et al [9] proposed a prevention method for sudden lines failures by combining the fire risk index, sensing hotspots near the power line and vegetation factors. Unlike the perspectives of previous research, TLTFIW is considered as an evolution process in this paper, including wildfires occurring, monitoring, extinguishing, spreading, transmission lines tripping and re-closing failure, and studying the potential risks in this evolution process is the core of this work.

2. The assessment algorithm of TLTFIW
A framework for the algorithm proposed of TLTFIW is described here, including current situation, the assessment algorithm of TLTFIW and purpose et al, which is shown in Fig. 1. In order to express the process of the event more intuitively and discover the potential risks in each link, the assessment algorithm, which is core in the framework, is developed, and it consists of three parts: the ETA of TLTFIW, the FTA of initiating event [10] and each subsequent event in the event tree and the fuzzy FTA with trapezoidal fuzzy number [11], which will be elaborated below.

2.1. Establishing event tree
ETA is a systems engineering approach which deduce the consequences following the chronological order of fault development. According to the characteristics of the evolution process of TLTFIW, wildfires occurring is determined as the initiating event (IE), followed by early-monitoring, extinguishing, spreading, transmission lines tripping, and re-closing failure, which are represented by E1-E5, respectively.

2.2. Establishing fault tree
To analysis the potential risk in the links of event tree established comprehensive, IE, E1, E2, E3, E4 and E5 are studied by FTA. Wildfires early-monitoring is the sufficient condition of wildfires extinguishing, as well as the best opportunity to reduce disaster damage. It’s difficult to extinguish when wildfires develop on a large scale. Fig. 2 and Table 1 respectively show the fault tree and related meaning of traditional wildfires early-monitoring methods including patrol, observation station and satellite monitoring. In addition, the fault tree of wildfires extinguishing consisting cooling method, isolation method and suffocation method are shown in Fig. 3 and Table 2 gives the related meaning.
Figure 2. Wildfires early-monitoring fault tree.

Table 1. Meanings of BEs in the wildfires early-monitoring fault tree.

| Symbol | Meaning                  | Symbol | Meaning                  |
|--------|--------------------------|--------|--------------------------|
| $T_1$  | Wildfires early-monitoring | $X_2$  | Satellite monitoring     |
| $M_1$  | Patrol                   | $X_3$  | Ground patrol            |
| $X_1$  | Observation station      | $X_4$  | Aviation patrol          |

Figure 3. Wildfires extinguishing fault tree.

Figure 4. Wildfires spreading fault tree.

Table 2. Meanings of BEs in the wildfires extinguishing fault tree.

| Symbol | Meaning                  | Symbol | Meaning                  |
|--------|--------------------------|--------|--------------------------|
| $T_1$  | Wildfires extinguishing  | $X_4$  | Fire in advance          |
| $M_1$  | Cooling method           | $X_5$  | Manual beating           |
| $M_2$  | Isolation method         | $X_6$  | Turn over the raw soil   |
| $M_3$  | Suffocate method         | $X_7$  | Fire forest belt         |
| $X_1$  | Purling                  | $X_8$  | Strong breeze            |
| $X_2$  | Chemical spraying        | $X_9$  | Soil covering            |
| $X_3$  | Wet soil                 | $X_{10}$ | Blasting                |

Table 3. Meanings of BEs in wildfires spreading fault tree.

| Symbol | Meaning                  | Symbol | Meaning                  |
|--------|--------------------------|--------|--------------------------|
| $T_1$  | Wildfires spreading      | $X_2$  | Gale                     |
| $M_1$  | Wind                     | $X_3$  | High slope Angle         |
| $M_2$  | Slope type               | $X_4$  | Upslope                  |
| $M_3$  | Vegetation               | $X_5$  | Low flammability of vegetation |
| $X_1$  | The wind blow to power grids | $X_6$  | Low water content of vegetation |
When the wildfires occur, they will spread quickly. Micrometeorology and topography have attracted extensive attention [12]. Based on this, the influence of wind, slope type and vegetation are selected as the intermediate event of wildfires spreading fault tree, as shown in Fig. 4 and the related meaning is given in Table 3.

The highest temperature of flames can reach 1200°C in wildfires, and the highest temperature hot smoke can reach over 520°C, furthermore, the fire pillar can grows up to as high as 30 m in the forest. Under this circumstance, transmission lines is prone to discharge or even trip [13]. Besides, the deformation of insulators induced by high temperature accounts for transmission lines tripping. Therefore, the transmission lines tripping fault tree is constructed, as shown in Fig. 5 and related meaning is shown in Table 4.

| Symbol | Meaning                                      | Symbol   | Meaning                                      |
|--------|----------------------------------------------|----------|----------------------------------------------|
| $T_1$  | Transmission lines tripping                  | $X_3$    | The transmission lines discharge to the buildings |
| $M_1$  | Discharge accident occurred on the transmission lines | $X_4$    | The transmission lines discharge to the Plants and animals |
| $X_1$  | High temperature induced deformation of insulators | $X_5$    | The transmission lines discharge to the point of the electric transmission pole tower |
| $X_2$  | The transmission lines discharge to the ground |          |                                              |

After transmission lines tripping, re-closing is the conventional operation. However, re-closing failure of transmission lines is the frequent phenomenon after wildfires [14]. Equipment hardware damage and existing phase fault among transmission lines are considered as the main reason for re-closing failure. The fault tree and related meaning of re-closing failure are respectively given in Fig. 6 and Table 5. Wildfires occurring is chosen for an example to show the analysis process, and the analysis of other events is alike so it is omitted here.

### 2.3. The calculation process of fuzzy fault tree

2.3.1. Expert evaluation. Each expert often evaluates BEs according to the previous work experience and common sense, so there would be errors. Therefore, three experts in related fields are invited to
evaluate the probabilities of fuzzy events for the more accurate assessment, and weights for each experts are determined according to Table 6. Table 7 presents the weights of different information indicators of each experts, which shows the weights of three experts are 0.438, 0.344 and 0.218, respectively. In addition, the common fuzzy evaluation language consists of very low (0.0, 0.0, 0.1, 0.2), low (0.1, 0.2, 0.2, 0.3), mildly low (0.2, 0.3, 0.4, 0.5), medium (0.4, 0.5, 0.5, 0.6), mildly high (0.5, 0.6, 0.7, 0.8), high (0.7, 0.8, 0.8, 0.9) and very high (0.8, 0.9, 1.0, 1.0).

Table 6. Weights of different information indicators.

| Constitution   | Classification | Score | Constitution | Classification | Score |
|----------------|----------------|-------|--------------|----------------|-------|
| Professional position | Professor | 5     | Professional position | ≥20          | 5     |
|                  | Associate professor | 4     |              | 15-20         | 4     |
|                  | Engineer        | 3     |              | 10-15         | 3     |
|                  | Technician      | 2     |              | 5≤            | 1     |
| Education level | Worker         | 1     |              |               |       |
|                  | PhD             | 5     |              |               |       |
|                  | Master          | 4     |              |               |       |
|                  | Bachelor        | 3     |              |               |       |
|                  | Junior college | 2     |              |               |       |
|                  | School          | 1     |              |               |       |

Table 7. Expert weighting.

| No. of expert | Professional position | Service time (Years) | Education level | Total score | Weights |
|---------------|-----------------------|----------------------|-----------------|-------------|---------|
| 1             | Professor=5           | 15-20=4              | PhD=5           | 5+5+4=14    | 0.438   |
| 2             | Associate Professor=4 | 6–9=2                | PhD=5           | 5+4+2=11    | 0.344   |
| 3             | Technician=2          | 5≤=1                 | Master=4        | 4+2+1=7     | 0.218   |
| Total         |                       |                      |                 | 32          |         |

2.3.2. Aggregating stage. Experts may have different cognitions of each evaluation object. Therefore, it is necessary to aggregate the opinions until a consensus reached [15]. The specific algorithm is described as follows. Calculating the degree of agreement ($DA$), the average of agreement ($AA$), the relative of agreement ($RA$) and the consensus coefficient ($CC$) degree of each pair of experts, the $DA$ function is defined as follows:

$$DA(A, B) = 1 - \frac{1}{4} \sum_{i=1}^{4} |a_i - b_i|$$  \hfill (1)

$$AA(E_i) = \frac{1}{n-1} \sum_{i \neq j}^{n} DA_{ij}(A_i, A_j)$$  \hfill (2)

$$RA(E_i) = \frac{AA(E_i)}{\sum_{i=1}^{n} AA(E_i)}$$  \hfill (3)

$$CC(E_i) = \beta \cdot W(E_i) + (1 - \beta) \cdot RA(E_i)$$  \hfill (4)
Where $DA(A,B) \in [0,1]$, and the larger $DA(A,B)$ represents the stronger similarity. $n$ is the sum of experts, and $AA(E_i)$ indicates the average agreement degree between an expert and all experts’ opinion. Here, $RA(E_i)$ is the weight of the average agreement degree for the opinion of an expert, and $\beta$ is relaxation factor and $\beta \in (0,1)$. We set $\beta = 0.5$ in this paper. Finally, the aggregated results of expert judgment $R_{AG}$ can be obtained as follows:

$$R_{AG} = \sum_{i=1}^{n} CC(E_i) \cdot R_i$$  \hspace{1cm} (5)

Here, $R_{AG}$ is the fuzzy number of BEs after aggregating, and $R_i$ is the trapezoid fuzzy probability given by an expert.

2.3.3. Analysis for importance degree of BEs. The importance degree of each basic event is related to the occurrence probability of the TE. Eq. (6) determines the calculation process.

$$I_{x_i} = \frac{P_{TE} - P_{TE}^{x_i=0}}{P_{TE}}$$  \hspace{1cm} (6)

Where $I_{x_i}$ is the importance degree of a BE; and $P_{TE}^{x_i=0}$ is the probability of TE when the occurrence probability of specific BE is zero.

3. An illustrative case for the assessment algorithm of TLTFIW
Transmission lines located in Xiangxi, Hunan Province are selected as analysis objects, and the tripping faults induced by wildfires of them are analysed by applying the algorithm of TLTFIW above. Fig. 7 displays the distribution of transmission lines located in Xiangxi, Hunan province.
3.1. The calculation process of fuzzy fault tree

3.1.1. Expert evaluation on the fault tree of wildfires occurring. After completing the investigation about the occurrence conditions of wildfires, three experts in related field are invited to judge BEs leading to the wildfires occurring, and their judgments are shown in Table 8. In addition, the expert judgments of other subsequent events are given in Table 8 as well.
Table 8. Expert judgments on BEs of each event.

| Expert judgments on BEs of wildfires early-monitoring. | Expert judgments on BEs of Wildfires extinguishing. |
|------------------------------------------------------|------------------------------------------------------|
| Be | Expert 1 | Expert 2 | Expert 3 | Be | Expert 1 | Expert 2 | Expert 3 |
| X1 | ML | ML | ML | X1 | M | M | MH |
| X2 | ML | M | ML | X2 | M | MH | M |
| X3 | M | M | ML | X3 | ML | ML | M |
| X4 | M | ML | ML | X4 | ML | M | ML |

Expert judgments on BEs of wildfires spreading.

| Expert judgments on BEs of wildfires spreading. | Expert judgments on BEs of transmission lines tripping. |
|-------------------------------------------------|------------------------------------------------------|
| Be | Expert 1 | Expert 2 | Expert 3 | Be | Expert 1 | Expert 2 | Expert 3 |
| X5 | MH | M | MH | X5 | MH | M | M |
| X6 | MH | H | MH | X6 | M | M | M |
| X7 | MH | VH | H | X7 | M | M | M |
| X8 | MH | MH | MH | X8 | VH | H | VH |
| X9 | VH | H | H | X9 | M | M | M |
| X10 | MH | MH | ML | X10 | M | M | M |

Expert judgments on BEs of re-closing failure.

| Expert judgments on BEs of re-closing failure. | EXPERT JUDGMENTS ON BEs TRANSMISSION LINE TRIPPING. |
|------------------------------------------------|--------------------------------------------------|
| Be | Expert 1 | Expert 2 | Expert 3 | Be | Expert 1 | Expert 2 | Expert 3 |
| X1 | VH | VH | H | X1 | MH | MH | M |
| X2 | MH | MH | H | X2 | MH | H | MH |
| X3 | VH | VH | VH | X3 | H | H | VH |
| X4 | MH | H | MH | X4 | H | MH | H |

3.1.2. Aggregate calculation of expert opinions. According to the algorithm of fuzzy fault tree mentioned in section 2.3, aggregating stage of the basic event X1 in the re-closing failure fault tree is conducted, which includes the calculations such as degree of agreement (DA), average agreement degree (AA), relative agreement degree (RA), etc. The aggregating calculation process of basic events X1 is shown in Table 9 and the calculations for other BEs are the same, so they are omitted.

Table 9. Aggregating calculation of basic events X1.

| Be | Expert | F | RA(E1) | DA12 | DA13 | DA23 | RAG |
|----------------|----------|----------------|---------|---------|---------|---------|---------|
| A1 | VH | (0.8,0.9,1.0,1.0) | 0.3409 | 1.0000 | 0.8750 | 0.8750 | 0.9375 |
| A2 | VH | (0.8,0.9,1.0,1.0) | 0.3409 | 0.8750 | 0.8750 | 0.8750 | 0.9375 |
| A3 | H | (0.7,0.8,0.8,0.9) | 0.3182 | 0.8750 | 0.8750 | 0.8750 | 0.9375 |
| AA(E1) | 0.9375 | W(E1) | 0.438 | 0.3895 | 0.3425 | 0.2681 |
| AA(E2) | 0.9375 | W(E2) | 0.344 | 0.3425 | 0.2681 |
| AA(E3) | 0.8750 | W(E3) | 0.218 | 0.2681 |

\[ R_{RAG} = CC(E1) \times R_1 + CC(E2) \times R_2 + CC(E3) \times R_3 = (0.7732, 0.8732, 0.9464, 0.9732) \]

3.1.3. Calculating the probability of the subsequent events. Due to the numbers of minimum cut sets are too numerous, the minimum path sets are used to calculate the probability of TE in the wildfires occurring fault tree. According to the calculation results, the occurrence probability of early wildfires early-monitoring (E1), wildfires extinguishing(E2), wildfires spreading (E3), transmission lines tripping (E4) and re-closing failure (E5) are 1.000%, 3.800%, 13.50%, 10.25% and 15.40%, respectively.

3.2. Event tree analysis of TLTFIW

According to the occurrence probability of each subsequent event obtained through the algorithm above, the probability of the result events are calculated. Fig.8 intuitively shows the occurrence probability of events in the tree of TLTFIW. The severity degree of the consequent events are judged according to the damage degree of wildfires to the transmission lines. Since this paper focus on the transmission lines
tripping, C₂ and C₆ are attached special attention. Although the other consequence events have a certain severity degree, they aren’t analysed.

| IE:          | E₁: Early wildfires monitoring | E₂: Wildfires extinguishing | E₃: Wildfires spreading | E₄: Transmission lines tripping | E₅: Re-closing failure | Consequence |
|--------------|-------------------------------|-----------------------------|------------------------|--------------------------------|-----------------------|-------------|
|              | Y(1.000%)                     | Y(3.800%)                   | Y(10.25%)              | Y(15.40%)                      | C₁                    | C₂(2.050×10⁻⁵) |
| Wildfires occurring | N(96.20%)                    | N(99.00%)                   | N(96.20%)              | Y(13.50%)                      | C₃                    | C₄          |
|              | Y(13.50%)                     | Y(13.50%)                   | Y(15.40%)              |                                 | C₅                    | C₆(2.110×10⁻³) |
|              | Y(10.25%)                     | Y(15.40%)                   |                         |                                 | C₇                    | C₈          |
|              | Y(15.40%)                     |                             |                         |                                 | C₉                    |             |

**Figure 8.** The probability of events in the tree of **TLTFIW**.

Clearly, the probability of C₆ is much larger than that of C₂ according to Fig. 8, which is mainly due to the occurrence of E₁ and E₂. Therefore, it is effective to reduce the probability of tripping by increasing the success rate of them. However, the probability of wildfires early-monitoring is low due to the relative underdeveloped monitoring system in Xiangxi, Hunan province, and the benefit of improving local relevant detection capability is relatively low, which reflects that wildfires early-monitoring is difficult. In addition, once ignited, usually, wildfires will aggravate in a few minutes, and it is extremely difficult to extinguish through artificial means, which lead to the low occurrence probability of E₂, which is also hard to increase. The occurrence probability of E₃, E₄, and E₅ is larger than that of E₁ and E₂, which contributes the high occurrence probability of C₆ and C₂. Meantime, wildfires occurring is the initiating event (IE) in the event tree, which is also important. Therefore, the influence of the initiating event (IE) and the subsequent events E₃, E₄ and E₅ need to be intensively analysed in the evolution of **TLTFIW**, and it is necessary to further analyse the importance degree of the BEs of their fault trees to discover the key events leading to higher risk.

3.3. **Analysis for importance degree of BEs**

According to the Fig. 9, the importance degree of ‘The good combustion characteristic of vegetation (X₅)’, ‘High slope Angle (X₃)’, ‘High wind (X₂)’ are relatively high, and the reasons are as follows: the selected area is located in the transition region of the second and third steps of China, which is mountain topography. In addition, the subtropical monsoon humid climate with obvious continental characteristics leads to the frequent occurrence of windy weather. It should be noted that the kinds of natural trees is various in the forest, most of which are more flammable, due to meteorological conditions in Xiangxi, Hunan province and the pine tree widely distributes particularly. Therefore, the artificial selection of tree species and increasing the area of tree species with strong fire resistance is the effective means to reduce wildfires spreading.
Fig. 9 shows that ‘The transmission lines discharge to the Plants and animals (X4)’, ‘The transmission lines discharge to the point of the electric transmission pole tower (X5)’ and ‘The transmission lines discharge to the ground (X2)’ are relatively high. It is found that the forest coverage rate reached 70.24% in Xiangxi and much of the transmission lines distributes over the forest. Therefore, it is necessary to prune the trees and vegetation which affect the safety operation of transmission lines, and optimize the lines layout at a low height above the ground. In addition, there is a need to strengthen the safety supervision of lines, especially the position of the prominent part of electricity poles close to transmission lines. Finally, reducing the possibility of transmission lines tripping is expected by the above measures.

Fig. 10 shows that ‘The transmission lines discharge to the Plants and animals (X4)’, ‘The transmission lines discharge to the point of the electric transmission pole tower (X5)’ and ‘The transmission lines discharge to the ground (X2)’ are relatively high. It is found that the forest coverage rate reached 70.24% in Xiangxi and much of the transmission lines distributes over the forest. Therefore, it is necessary to prune the trees and vegetation which affect the safety operation of transmission lines, and optimize the lines layout at a low height above the ground. In addition, there is a need to strengthen the safety supervision of lines, especially the position of the prominent part of electricity poles close to transmission lines. Finally, reducing the possibility of transmission lines tripping is expected by the above measures.

According to Fig.11, the importance degree of ‘Instantaneous multiple single-phase failures (X3)’ is the highest and it is the main reason for the re-close failure. Researches show that the reclosing device connected to a transmission line occurs single-phase transient earth fault under the action of wildfires. Once the fault happens several times, single phase reclosing would be invalid. Though transient or permanent fault cannot be completely avoided for each transmission lines, the probability of such fault can be reduced by optimizing the insulation design and strengthening the protection of insulation device of transmission lines. In addition, improving the device quality and line accuracy and strengthening the maintenance and monitoring of lines are also effective.

4. Conclusion

TLTFIW is considered as a result of evolution of various events, and the development process is divided into six stage including wildfires occurring (IE), early wildfires early-monitoring (E1), Wildfires
extinguishing (E2), Wildfires spreading (E3), transmission lines tripping (E4), and re-closing failure (E5).
An assessment algorithm is proposed here to intuitively describe the development process and analysis
the potential risk by combining ETA, FTA and trapezoidal fuzzy theory. In addition, an illustrative case
is provided to show the applicability of algorithm proposed. The results indicate that the occurrence
probability of transmission tripping is $2.130 \times 10^{-3}$ and some measures are proposed to reduce the
potential risk of E3, E4 and E5 events in the selected area.

Acknowledgements
This work is financially supported by the National Key Research and Development Project of China
[grant numbers 2016YFC0802500]; National Natural Science Foundation of China (NSFC) [grant
numbers 71790613].

References
[1] Ming Z, Lilin P, Qiannan F and Yingjie Z. Trans-regional electricity transmission in China: Status,
issues and strategies. Renewable and Sustainable Energy Reviews. 2016; 66: 572 - 583.
[2] Choobineh M, Ansari B and Mohagheghi S. Vulnerability assessment of the power grid against
progressing wildfires. Fire Safety Journal.2015; 73: 20 - 28.
[3] Xu K, Zhang X, Chen Z, Wu W and Li T. Risk assessment for wildfire occurrence in high-voltage
power line corridors by using remote-sensing techniques: a case study in Hubei Province,
China. International Journal of Remote Sensing.2016; 37: 4818 - 4837.
[4] CHATENOUX BPP. Biomass fires: preliminary estimation of ecosystems global economic losses.
https://archive-ouverte.unige.ch/unige:32231. 2013.
[5] Shi S, Yao C, Wang S and Han W.A Model Design for Risk Assessment of Line Tripping Caused
by Wildfires. Sensors. 2018; 18: 1941.
[6] Ansari B and Mohagheghi S. Optimal energy dispatch of the power distribution network during
the course of a progressing wildfire. International Transactions on Electrical Energy Systems.
2015; 25: 3422 - 3438.
[7] Mitchell JW. Power line failures and catastrophic wildfires under extreme weather conditions.
Engineering Failure Analysis. 2013; 35: 726 - 735.
[8] Wang T, Tang Z and Wang X, et al. Whether the High-Voltage Transmission Lines Have Enough
Load Capacity After Wildfire. Proceedings of the 5th International Conference on Electrical
Engineering and Automatic Control. Springer Berlin Heidelberg, 2016.
[9] Lu J, Guo J, Jian Z and Xu X. Optimal Allocation of Fire Extinguishing Equipment for a Power
Grid Under Widespread Fire Disasters. IEEE Access.2018; 6: 6382 - 6389.
[10] Nusbaumer O and Rauzy A. Fault tree linking versus event tree linking approaches: a reasoned
comparison. Proceedings of the Institution of Mechanical Engineers, Part O: Journal of Risk
and Reliability. 2013; 227: 315 - 326.
[11] Li Y, Mi J, Liu Y, Yang Y and Huang H. Dynamic fault tree analysis based on continuous-time
Bayesian networks under fuzzy numbers. Proceedings of the Institution of Mechanical
Engineers, Part O: Journal of Risk and Reliability. 2015; 229: 530 - 541.
[12] Salis M, Del Giudice L and Arca B, et al. Modeling the effects of different fuel treatment mosaics
on wildfire spread and behavior in a Mediterranean agro-pastoral area. Journal of Environment
Management. 2018; 212: 490 - 505.
[13] Zhong Yuan YZ. Study on causes and countermeasures of transmission line tripping induced by
wildfires. China Southern Agricultural Machinery. 2017; 79-83. (in Chinese).
[14] Peng Zheng GYHB. Study on the failure reason and countermeasures of single-phase reclosing
of transmission lines. Technology Wind. 2013: 61. (in Chinese).
[15] Hsi-Mei Hsu and Chen-Tung Chen. Aggregation of fuzzy opinions under group decision making.
Fuzzy Sets and Systems. 1996; 79: 279 - 285.