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Electrical Fire Hazards Analysis of Electric Iron and Heater Using Fault Tree Analysis

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Abstract : The primary goal of this study is to analyze fire hazards of electric home appliances such as electric iron and electric heater using fault tree analysis(FTA). A fault tree(FT) is constructed and used to analyze fire hazards in electric home appliances. The fault tree is built from events that may occur in electric home appliances. The failure rate of basic events are derived from the value of experimental results and reference. And an algorithm analyzing fire in electric home appliances is suggested. We show how fault tree analysis, carried out by means of failure rate, is able to diagnose fire hazards of electric home appliances in a precise manner. We present numerical results such as fire probability of electric home appliances, importance measure, fire cause, etc. It can be helpful in preventing the fire hazards in electric home appliances.

Key words : electrical fire, fault tree, fire hazards

1. Introduction

Electricity is energy that becomes a motive power of life and industry. Demand for electrical power is increasing every year because of its convenience and stability. Thusdevices become more various and complicated. And the electrical fire is high for all that electricity makes rapid progress. Electric home appliances are generally used by common people such as child, aged person and so on. So electric fire safety is more strengthened in electric home appliances and a number of studies have been conducted to reduce electrical fire such appliances[1-2]. However, electrical fires still occur in electric home appliances. Especially, electric fire hazard of electric iron and heater is high because they are usually used to high temperature.

Fault tree analysis(FTA) is an applicable and useful analysis tool; it is an analytical technique used for identifying and classifying hazards, and calculating system reliability for both simple and complex engineering systems. FTA is a well known engineering approach in the reliability and safety domain. It is one of the most widely used by practitioners[3].

In this paper, therefore, we present a study on the analysis of electrical fire hazards using FTA electric home appliances such as electric iron and heater. We consist of FT which is constructed of factors leading to electric fire and analyze fire hazards for these appliances quantitatively. We suggest fire probability, important factors and cause leading to electric fire according to analysis by constructed FT.

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2. FTA

The fault tree is a tool to identify and assess all combinations of the undesired events in the context of the system operation and its environment that can lead to the undesired state of the system. The undesired state of the system is represented by a top event. The logical gates integrate the primary events to the top event. The primary events are the events, which are not further developed, e.g. the basic events and the house events. The basic events are the ultimate parts of the fault tree, which represent the undesired events, e.g. the component failures, the missed actuation signals, the human errors, the unavailability due to the test and maintenance activities, the common cause contributions.

The house events represent the conditions set either to true or false, which support the modeling of connections between the gates and the basic events and enable that the fault tree better represents the system operation and its environment[4-5].

The fault tree is mathematically represented by a set of Boolean equations:

$$G_i = f(G_p, B_j, H_s); i,\ p \in \{1...P\},\ J \in \{1...J\},\ s \in \{1...S\} \quad (1)$$

Where G_p is gate p, B_j is basic event J and H_s is house event s.

The qualitative analysis identifies the minimal cut sets(MCS), which are combinations of the smallest number of basic events, which if occur simultaneously, may lead to the top event. Top event probability Q_{TE} is calculated by

$$Q_{TE} = \sum_{i=1}^{n} Q_{MCS_i} - \sum_{i<j} Q_{MCS_i \cap MCS_j} - \cdots + \sum_{i<j<k} Q_{MCS_i \cap MCS_j \cap MCS_k} - \ldots + (-1)^{n-1} Q \bigcap_{i=1}^{n} MCS_i \quad (2)$$

Where Q_{MCS} is probability of occurrence of MCS. It is calculated by

$$Q_{MCS_i} = Q_{B1}Q_{B2}|Q_{B1}Q_{B2}|Q_{B1} \cap Q_{B2} \cdots Q_{Bm}|Q_{B1} \cap Q_{B2} \cap \ldots \cap Q_{Bm-1} \quad (3)$$

Or where under assumption that the basic events are mutually independent:

$$Q_{MCS_i} = \prod_{j=1}^{m} Q_{B_j} \quad (4)$$

Where Q_{Bj} is probability of occurrence of basic event B_j.

If the minimal cut sets are not assumed as mutually independent, the second and the next items in equation (2) are written as follows:

$$Q_{MCS_i \cap MCS_i} = Q_{MCS_i} Q_{MCS_j} | Q_{MCS_i} \quad (5)$$

$$Q_{MCS_i \cap MCS_j \cap \ldots MCS_n} = Q_{MCS_i} Q_{MCS_j|MCS_i} \cdots Q_{MCS_n|MCS_i \cap MCS_j \cap \ldots \cap MCS_{n-1}} \quad (6)$$

If the minimal cut sets are assumed as mutually independent, the second and the next item in equation (2) are written as:

$$Q_{MCS_i \cap MCS_j} = Q_{MCS_i} Q_{MCS_j} \quad (7)$$

$$Q_{MCS_i \cap MCS_j \cap \ldots \cap MCS_n} = Q_{MCS_i} Q_{MCS_j} \ldots Q_{MCS_n} \quad (8)$$

In either case, equation (2) can be simplified and approximated with its first item:

$$Q_{TE} = \sum_{i=j}^{n} Q_{MCS_i} \quad (9)$$

Where λ_p is failure rate of the equipment modeled in the basic event p.

One of the most important outputs of an FTA is the set of importance measure that are calculated for the FT events. Importance measures help to identify weak links in the system design and the components that will provide the most cost-effective mitigation. The FT importance measures establish the significance for all the events in the fault tree in terms of their contributions to the FT top event probability. Both intermediate gate events as well as basic events can be prioritized according to their importance. Top event importance measures can also be calculated that give the sensitivity of the top event probability to an increase or decrease in the probability of any event in the fault tree. Both absolute and relative importance measure can be calculated. What is often useful about the top event importance measures is that they generally show that relatively few events are important contributors to the top event probability. The kind of importance measure is probability importance measure, criticality importance measure and so on[6].

In this study, we evaluate fire causes leading to fire using probability importance measure and criticality importance measure.

The probability importance measure $I_p(j)$is calculate by

$$I_p(j) = \frac{Q_{TE}}{q_j} \quad (10)$$

The criticality importance measure is calculated by

$$I_c(j) = \frac{q_j}{Q_{TE}} I_p(j) \quad (11)$$

Where is probability of occurrence of basic event j.

We analysis electrical fire hazards using these equations such as fire probability, cause of contributing fire and so on.

3. Electrical Fire Hazards Analysis using FTA

3.1 Top event

The top event of FT is undesirable or unexpected event of system. The top event may be assumed by the safety analyst to be of sufficient importance to warrant the time and effort of the fault tree. In addition to assuming a top undesired event for the origin of the tree development, the analyst must decide upon the state of the system to be analyzed for the occurrence of

Table 1. Failure rate basic events for electric iron

No. of Event	Basic event	Failure rate (failures/10^6hr)
1	Overload	2.3
2	Half Disconnection	0.16
3	Conjunction Failure	0.3221
4	Contact Failure	0.0394
5	Automatic Controller (bimetal) Failure	11.4
6	Fail to operate Temp. Fuse	2.61
7	Power Switch Failure	1.2

Table 2. Failure rate basic events for electric heater

No. of event	Basic event	Failure rate (failures/10^6hr)
1	Overload	2.3
2	Half Disconnection	0.16
3	Conjunction Failure	0.3221
4	Contact Failure	0.0394
5	Fail to operate Temp. Fuse	2.61
6	Power Switch Failure	1.2
7	Upset Safety Switch Failure	1.14
8	False Heater Position	17.8

the top event[7].

In this paper, the top event is decided on 'fire' because this study is analyzing fire hazards in electric home appliances. And we calculate probability of top event, important etc.

3.2 Basic events

We analyze factor leading to fire in electric iron and investigate fire case of these appliances. We constitute basic events based on these results and determine failure rate according to basic events.

Table 1 and table 2 are basic events and failure rate of those for electric iron and electric heater, respectively. Each basic event is consisted of causes leading to top event and the failure rate of basic events consisted of based on 'IEEE Std. 493', 'Military Handbook 217F' and so on[8-11].

3.3 FT Building

Fig. 1 and fig. 2 show FT structure based on basic events for electric iron and electric heater, respectively. As shown fig. 1, in this paper, we consider that fire of electric iron is caused by heat accumulation or plate overheat. Each event is linked intermediate events which is linked subordinate events such as intermediate events or basic events. Also as shown fig. 2, in this paper, we consider that fire of electric heater is caused by heat accumulation or overheat that is similar to electric iron.

We analyze electrical fire hazards using constructed FT such fig. 1 and fig. 2.

3.4 Minimal cut set(MCS)

Cut set(CS) is one of the key products from FTA. They identify the component failures and/or event combinations that can cause the top event to occur. CSs also provide one mechanism for probability calculations. Essentially, CSs reveal the critical and weak links in a system design by identifying safety problem components, high probability CS, and where intended safety or redundancy features have been bypassed.

Minimal cut set(MCS) is cut set that has been reduced to the minimum number of events that cause the top event[12].

Table 3 shows MCSsfor electric iron and heater.

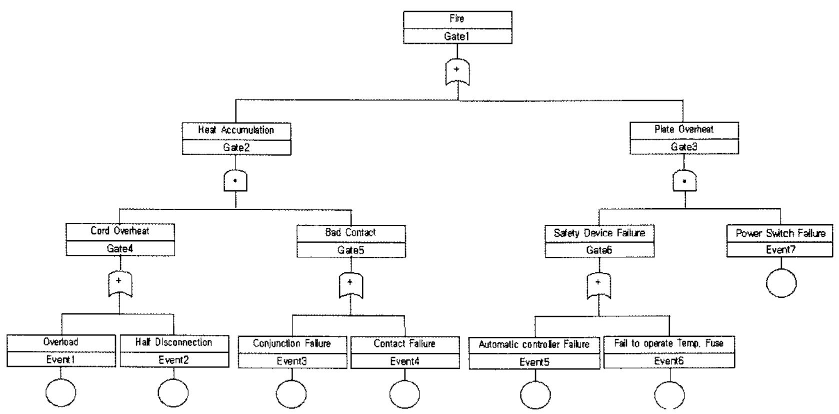

Fig. 1. Fault tree for electric iron

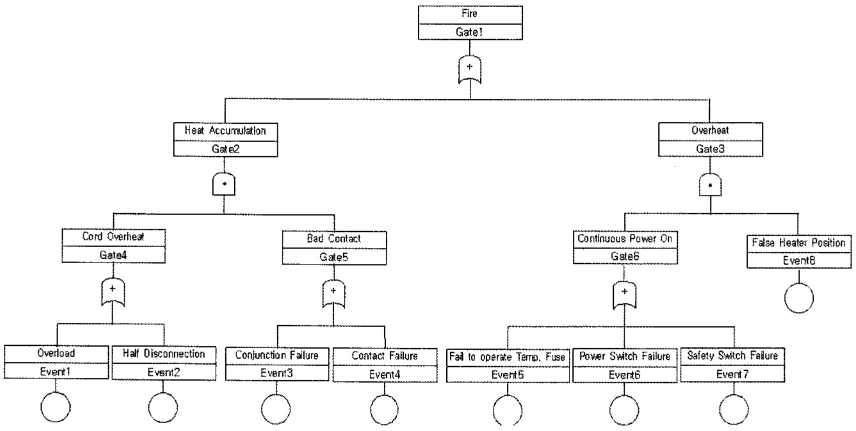

Fig. 2. Fault tree for electric heater

Table 3. Minimal cuts sets

No.	Electric iron	Electric heater
1	Event 1, 3	Event 1, 3
2	Event 1, 4	Event 1, 4
3	Event 2, 3	Event 2, 3
4	Event 2, 4	Event 2, 4
5	Event 5, 7	Event 5, 8
6	Event 6, 7	Event 6, 8
7		Event 7, 8

Approximately 30 % of whole MCSs have an effect occurrenceof top event for electric iron. And 40% of whole MCSs have an effect in case of electric heater. Especially, the most important MCS is 'Automatic Controller Failure' and 'Power Switch Failure' for electric iron, and 'Fail to operate Temperature Fuse' and 'False heater position' for electric heater. The result proves that event 5 and 7 has extremelyhigh contribution for electric iron and event 5 and 8 has extremely high contribution for electric heater. Fig. 3 shows probability according to each MCS. As shown fig. 3, MCS's probability of electric iron is higher than that of electric heater.

3.5 Quantitative analysis

The probability of top event, that is, unreliability of top event is calculated. We consider that the electric home appliances are unrepairable because appliance damaged by fire is not able to repair. The probability of top event is fire probability because tope event is fire. The fire probability of electric iron and heater are 1.76×10^{-5}, 8.81×10^{-5} when operating time is 1000 hours, respectively. The fire probability of electric heater is higher than that of electric iron. Fig. 3 shows fire probability according to operating time. As shown fig. 3, the fire probability is more and more increase according to operating time. Because the failure rate is not applied to values of real environmental condition, calculated fire probability may somewhat differ from values of electric home appliances used in domestic.

Fig. 5 and fig. 6 are probability and criticality importance measure for electric iron and heater, respectively. As shown fig. 5, probability of event 5, 6 and 7 have the high effect on probability of top event for electric iron

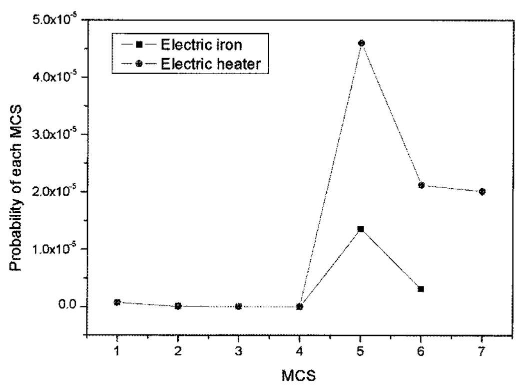

Fig. 3. Probability of each minimal cut sets

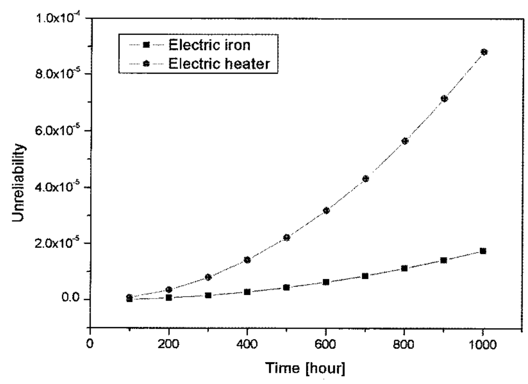

Fig. 4. Probability of top event according to time

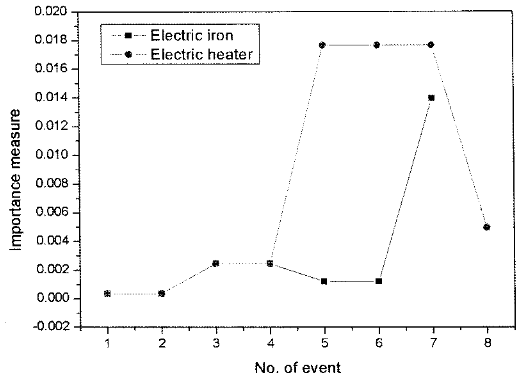

Fig. 5. Probability importance measure

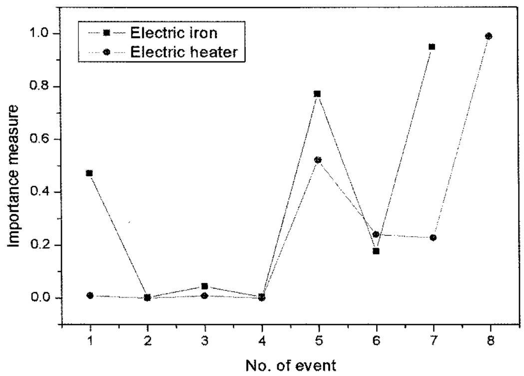

Fig. 6. Criticality importance measure

and event 7 has the extremely high effect on probability of top event for electric heater. This means that event 7 is extremely high contributor occurring fire in case of electric iron and event 5, 6 and 7 have most serious effect on occurrence of fire in case of heater.

As shown fig. 6, the criticality importance of event 5 and 7 are high for electric iron and that of event 5 and event 8 are high for electric heater. In case of electric iron, it proves that fire probability is reduced if reliability of automatic controller(bimetal) and power switch is increased. In case of electric heater, it proves that fire probability is reduced if reliability of temperature fuse is increased and heater stand is stable.

4. Conclusion

We presented analysis on the electrical fire hazards for electric home appliances using FTA. Electric home appliances considered in this paper are electric iron and electric heater. We built FT in which the top event is fire on those appliances. Our calculation was based on the FT quantitative data such as fire probability and importance measure, among others. The results showed that the fire probability is 1.76×10^{-5} for electric iron and 8.81×10^{-5} for electric heater for the given operating time of 1,000 hours. And power switch for electric iron and temperature fuse, power switch and safety switch for electric heater were found to have the most serious effect on occurrence of fire.

Because the failure rate used in this study is not derived from the actual environmental condition, these values may differ from true values. However, throughout this paper, we showed quantitatively fire hazards of electric home appliances such as electric iron and heater. The results and methods in this paper can be helpful in preventing fire hazards in electric home appliances. For the future, it is necessary to research fire hazards of various electric home appliances.

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