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Oil-immersed Transformer Failure Mode Analysis by Fault Tree and Preventive Measures

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Abstract

As the core power equipment, large oil-immersed transformers have been widely used in power plants and substations. But in recent years, oil-immersed transformer accidents have occurred frequently, resulting in serious consequences. Based on the oil-immersed transformer accident cases in recent years, the types of oil-immersed transformer accidents are divided, the characteristics are summarized, and the occurrence mechanism of oil-immersed transformer fire accidents is analysed. Countermeasures and technical measures to control oil-immersed transformer accidents.

Keywords

Power Transformer; Oil-immersed Transformer; Failure Modes; Fault Tree.

1. Introduction

Large-scale transformers play an important role in energy conversion in the process of power distribution and transmission. It is the most expensive and critical equipment in the power grid, the only way for thousands of households to pass through energy, and it is also the backbone of all walks of life in the national economy.

In order to avoid accidents in the power grid system, defensive work must be done. Once the transformer failure is caused, it will affect the normal production and the normal life of the people. And the outage and repair of large transformers will bring great economic losses. In addition, due to the diversity of transformer accidents, after the main contradiction is solved, the secondary contradiction will rise to the main contradiction.

This paper analyzes the types and characteristics of oil-immersed transformer accidents, summed up the occurrence mechanism, and put forward the countermeasures and technical measures to prevent and control oil-immersed transformer accidents.

2. Oil-immersed Transformer Failure Modes

Common failures of transformers can be classified into internal failures and external failures. Internal failures are various failures that occur inside the transformer tank, such as phase-to-phase short-circuit faults between windings, inter-turn short-circuit faults between winding resistances, and various ground failures, etc. External failures mainly include failures that occurred on the lead wires and various failures that occurred on the outer insulating sleeve of the oil tank of the transformer. The main types of external faults of the transformer include ground short-circuit faults, phase-to-phase short-circuit faults, and internal faults of the transformer caused by external factors or faults caused by winding deformation. [1].

In addition, transformer failures can also be divided into thermal faults and electrical faults by the nature of the transformer. Local overheating and temperature rise inside the transformer are common

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causes of thermal faults in the transformer. According to the severity of the transformer thermal fault, the thermal fault can be further divided into low temperature overheating, medium temperature overheating, and high temperature overheating. Electrical faults are divided into three types: partial discharge, sparking discharge, and high-energy arcing discharge. Electrical faults usually occur due to the high electric field strength inside the transformer. [2].

From the structural point of view, in addition to the auxiliary tap changer and external cooling system, the main components of the transformer include the cooler, core, windings, etc. All these groups and components are possible to fail. In order to improve the effectiveness of the analysis, in this report, I use the fault tree method for analysis mainly based on the difference in the likelihood of occurrence of each type of failure.

The top of the fault tree is the largest type of fault. Divide this type into layers in turn, and finally obtain the most basic and smallest types of faults that we are most easily perceivable. The main fault tree structure of a common transformer is shown in Figure 1.

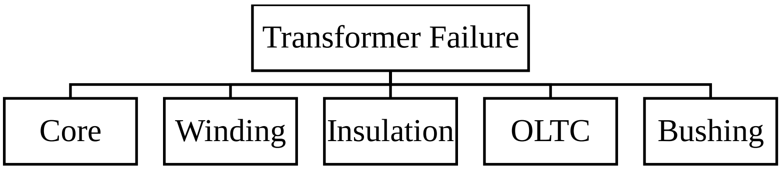

Figure 1. Transformer Main Fault Tree

3. Discussions on Transformer Failure Modes

In this section, each main failure mode in the main fault tree is divided into more basic sub-faults based on the causal relationship between the faults, thus forming a series of fault sub-trees.

3.1 Transformer Core

The iron core is the main magnetic circuit of the transformer and its mechanical skeleton. The iron core is composed of an iron core column and an iron yoke. The iron core column is covered with windings, and the iron core column is connected to form a closed magnetic circuit.

When grounding, it should be noted that only one point of the iron core shall be grounded, and only single-wire connections are allowed between the grounding parts. A closed loop may form if there are two or more grounding points in the iron core. When a relatively large magnetic flux passes through this closed loop, an induced electromotive force will be generated in the loop, and the induced electromotive force will cause an induced current, which is likely to cause the local temperature overheating, and burn out the iron core. The fault tree of the core is shown in the figure below. [3-5].

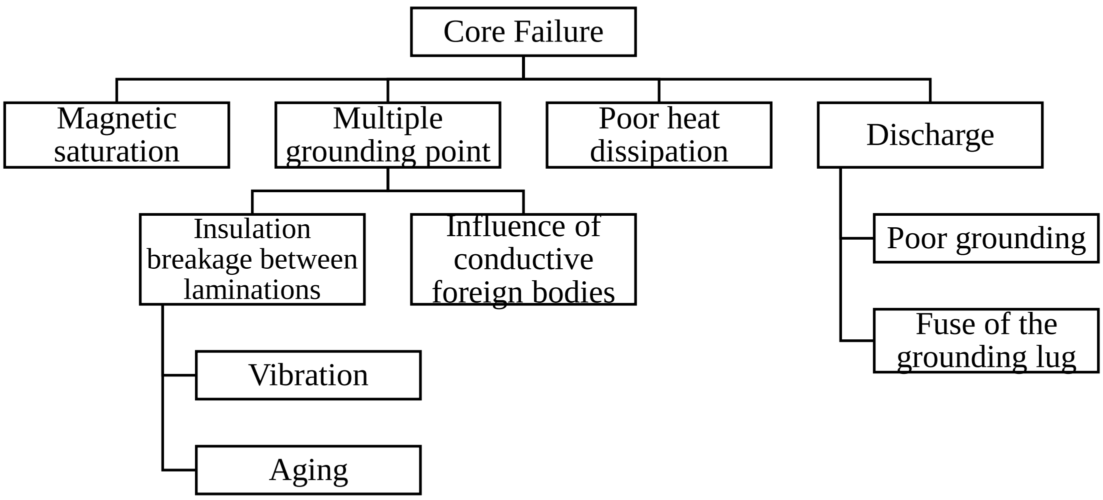

Figure 2. Transformer Core Fault Tree

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3.2 Winding

The winding of the transformer is the electric path, which is wound on the iron core column, and the outer side of the wire is insulated by paper or yarn-wrapped insulation. Power transformers of different capacities and electrical levels have different winding types and structures. The fault tree of the winding is shown in Figure 3. [5-8].

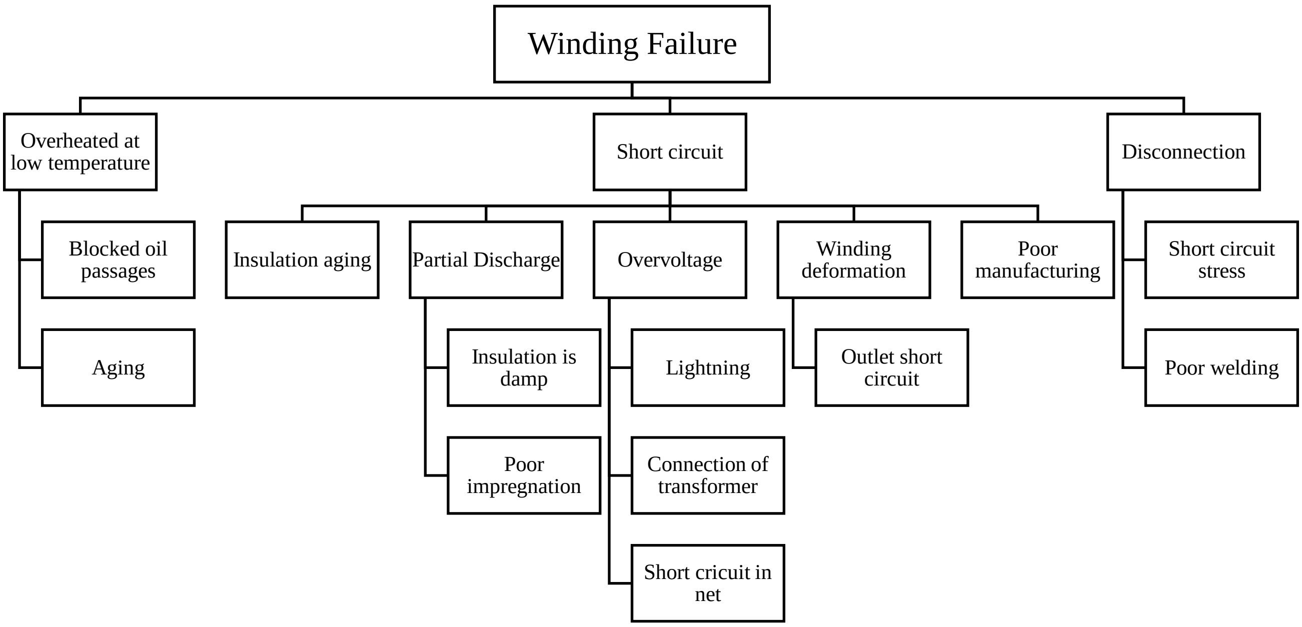

Figure 3. Transformer Winding Fault Tree

3.3 Insulation

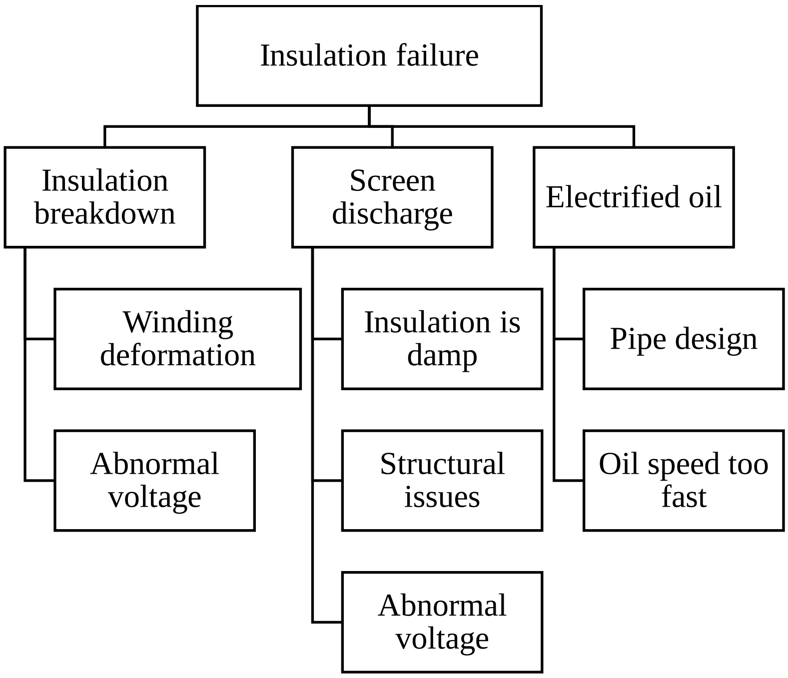

Figure 4. Transformer Insulation Fault Tree [5, 9-11]

3.4 Tap Changer

The characteristic of the on-load tap changer (OLTC) is that there is no need to cut off the power supply and regulates the voltage under the condition of running with a load. It has a large number of voltage regulation stages, which can stabilize the voltage of the power grid at each load center and

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improve the quality of the power supply. Therefore, OLTC is used at important power supply places. The fault tree of OLTC is shown in Figure 5. [5, 12-13].

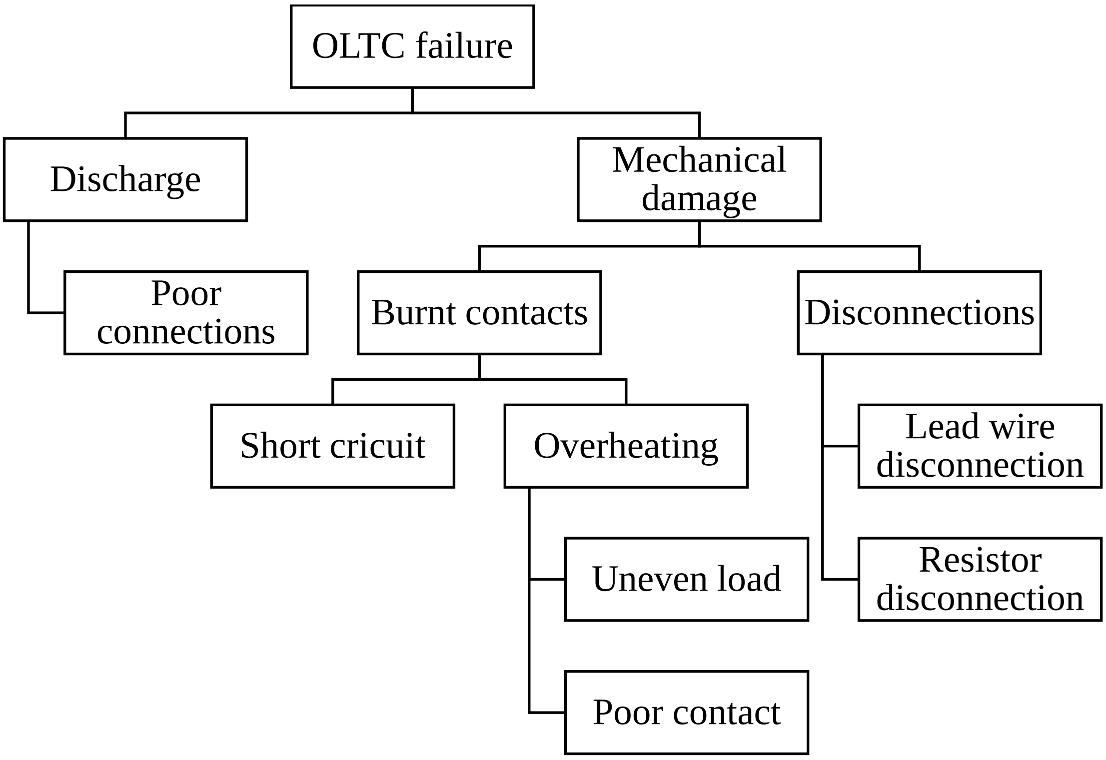

Figure 5. Transformer OLTC Fault Tree

3.5 Bushing

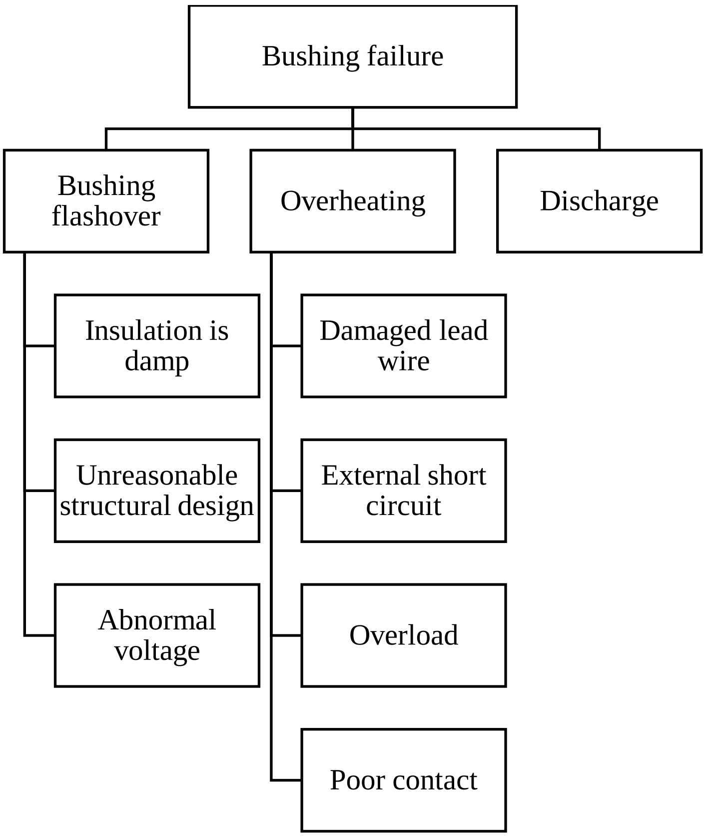

Figure 6. Transformer Bushing Fault Tree [5, 14-17]

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4. Transformer Failure Modes Likelihood

In this section, transformer fault statistics of several countries are collected to analyze the likelihood of each failure mode. First, for Australia, the 1996 Australian and New Zealand Failure Survey covers 2906 power transformer units. The study shows that OLTC was the most common failure mode (25%), and the percentage of bushing and winding were both 16%. [17].

According to the 2012 CIGRE Transformer Reliability Survey, winding was the major cause of transformer failure among 60 transmission power transformers units (45%) and 118 distribution power transformer units (59%). [18].

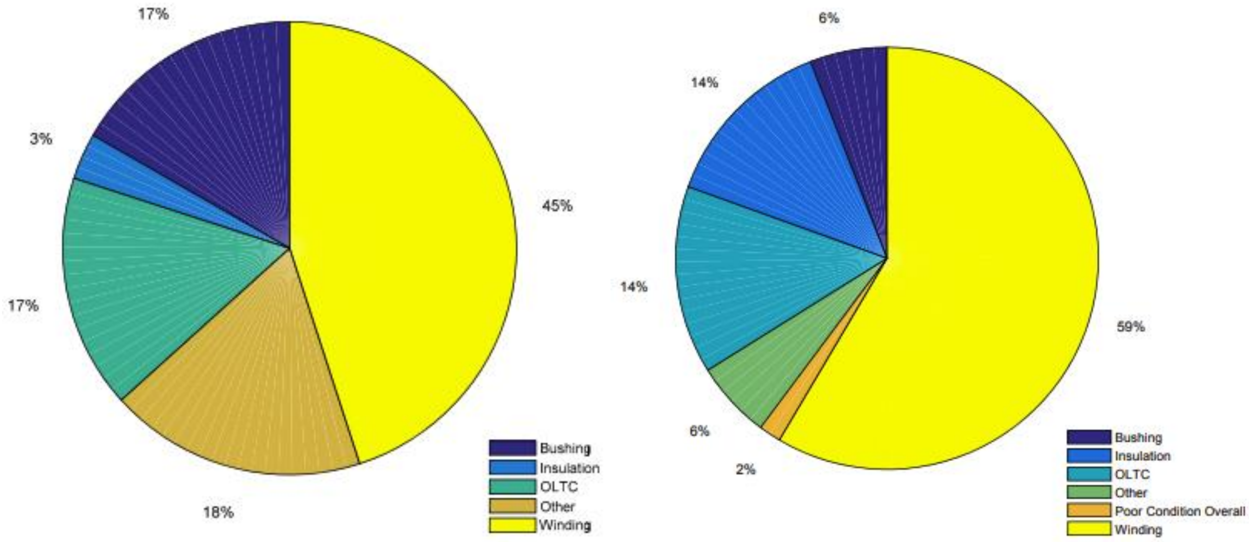

Figure 7. Percentage of Failure Modes for Transformers in Australia [18]

The South African Utility Eskom Survey statistically analyzed 200 power transformer failure in the period of 1996-2006 in South Africa. The report indicates that protection equipment, OLTCs, and bushings are the three most common failure modes for voltage power transformers, while unclassified faults, windings, and bushings were the top three failure modes for lower voltage power transformers. [17].

Besides, failure data acquihired by the CIGRE A2.37 covers 964 major failures of 58 utilities from 21 countries in 1996 to 2010. Statistics show that winding was the most prominent failure mode, and OLTC is the second. [20].

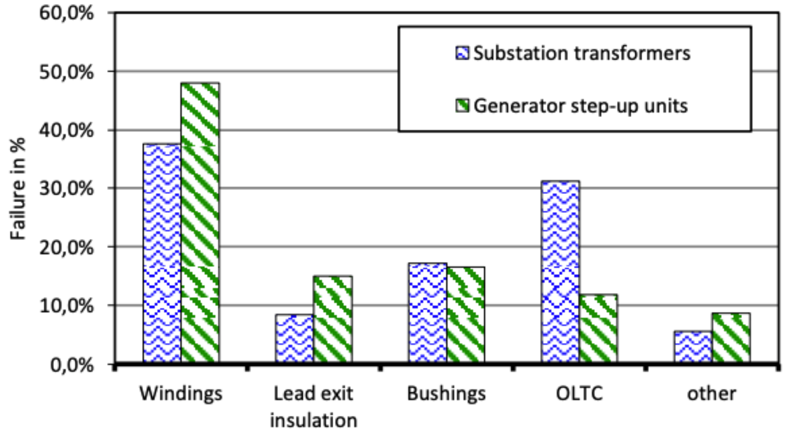

Figure 8. Percentage of Failure Modes for Transformers 1996 - 2010 [20]

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5. Transformer Failure Preventive Measures Analysis

Compared with other electrical equipment, transformers have fewer faults, and many accidents can be avoided through prevention and maintenance. However, once an accident occurs, it is necessary to reduce or interrupt the power supply to some users. In the absence of a backup transformer, it would cause serious losses to the power company.

Therefore, effective anti-accident measures should be adopted to prevent accidents, and for transformers that have failed, the cause and nature of the accident should be correctly judged according to the accident phenomenon, so that the accident can be handled quickly and correctly to prevent expansion.

5.1 Measures to Prevent Short-Circuit Accidents

In recent years, the capacity of the power system has continued to increase, and the technical parameters of transformers have also been improved. As the working voltage continues to rise and the capacity increases, the short-circuit capacity and short-circuit current of the system are also greatly improved. However, the transformer will inevitably encounter many problems during operation. Due to the high voltage and large capacity of the transformer, once a short-circuit accident occurs, the consequences will be very serious.

The following measures are mainly used to prevent short-circuit accidents of transformers in operation, which can be selected and adapted according to the actual conditions of the transformer and the operating environment: [1, 21-23].

When selecting a manufacturer, consideration should be given. Products that have passed the short-circuit test should be selected, unnecessary taps for voltage regulation should be reduced as much as possible, and the capacity should be selected reasonably.

If the transformers are operated in parallel, a protective self-input device could be added to reduce the short-circuit current.

To reduce the probability of a short circuit at the outlet of the low-voltage side of the transformers, an effective method is to install an insulating heat-shrinkable sleeve on the middle phase of the busbar bridge, and other effective protective measures can also be adopted.

Improve the maintenance and management of the low bus and the equipment linked to it. For example, enclose the bus bar with an insulating sheath, which can prevent small animals from entering and causing short circuits and other accidental short circuits.

Correct action rate of relay protection and its automatic device could be increased to prevent the protection of the device from refusing to operate, overstepping, or delaying tripping when an accident occurs.

5.2 Measures to Prevent Insulation Breakdown

If the transformer insulation is mixed with moisture, air or other impurities, accidents are likely to happen. To prevent the occurrence of such accidents, preparation work before putting transformers into use and regular maintenance during operation are very important. The following aspects could be proceeded.

First, the transformer must be well sealed when transporting and storing, and effective measures must be taken to prevent water from entering the transformer during the entire installation process of the transformer. In addition, the transformer spends most of its lifetime in operation. Therefore, the waterproofing work during the operation of the transformer must be done well. Leak detection tests shall be done regularly, and the sealing conditions of components must also be tested. [24-25].

Second, since the transformer installation is a complicated process, it is very likely that some residues will be left in the windlass cover. Therefore, it should be avoided as much as possible during installation. Moreover, after the installation is completed, the windlass cover should be inspected, and all the remaining debris should be removed. The iron core and coil with oil could be wished to remove residues. [25-26].

5.3 Measures to Prevent Deterioration of Transformer Oil

The management and supervision of transformer oil should be strengthened to keep the transformer oil in good quality. In addition, sealing and nitrogen-filling protection could be used to prevent deterioration of insulating oil. Membrane sealing is relatively simple to operate and maintain. However, for large-capacity transformers with membrane seals, oil shall be filed with caution to prevent false oil level and air from entering, to avoid fuel injection which cause severe gas protection malfunction when the temperature rises during operation. [27-28].

5.4 Feasibility of Prevention Actions

Considering the diversity of power transformer types, the failure prevention methods proposed above are relatively general, including improved management and maintenance. Although these methods can reduce the occurrence of failures, maintenance costs will inevitably increase.

At present, in the selection of maintenance strategy, most transformers are still using the traditional time-based maintenance (TBM). However, the value of the transformer and the failure rate should also be considered to make the most optimal maintenance decision. Therefore, condition-based maintenance (CBM) shall be used to improve the feasibility of prevention and maintenance actions. [29].

6. Conclusion

When analyzing the source of transformer accidents, the basic principles and structure of the transformer shall be analyzed. The common transformer failure modes and their causes were organized in the fault trees, and the characteristics of the failure mode are summarized. Based on past statistical data, the likelihood of common transformer faults is analyzed. It is found that winding is the most common failure mode.

Preventive measures are proposed for common transformer accidents, and preventive methods are proposed for transformer short-circuit, insulation breakdown and transformer oil deterioration to reduce and eliminate accidents in transformer production, maintenance, design, and manufacturing.

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