Fault diagnosis of power transformer based on fault-tree analysis (FTA)

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Abstract. Power transformers is an important equipment in power plants and substations, power distribution transmission link is made an important hub of power systems. Its performance directly affects the quality and health of the power system reliability and stability. This paper summarizes the five parts according to the fault type power transformers, then from the time dimension divided into three stages of power transformer fault, use DGA routine analysis and infrared diagnostics criterion set power transformer running state, finally, according to the needs of power transformer fault diagnosis, by the general to the section by stepwise refinement of dendritic tree constructed power transformer fault

1. Introduction
Power transformer is an important power transmission equipment in power grid. Its operation is directly related to the safety and power supply reliability of hair and power supply system [1-2]. With the increasing of power system scale and single transformer capacity, the losses to the national economy caused by the fault of power transformer is also growing. Thus making reliability analysis and risk assessment of transformer is an increasingly important issue [3-5].

Fault diagnosis of power transformer is under the situation of device hanging hood and not disintegration, based on experience and data, determine the state of transformer through certain technical means and track diagnosis and estimate the existing fault and evolution of transformer [1, 6]. Fault detection and diagnosis of the running transformer is a key channel to improve the safety and power supply reliability of power system [1, 6-7].

References [8-10] summed up the failure modes of power transformer, and fuzzy control carried out hazard assessments. References [11-12] discussed the way to build transformer fault diagnosis system based on artificial neural networks and fuzzy mathematics. References [13] discussed the application of oil gas analysis in fault diagnosis of transformer. References [14-15] researched fault diagnosis and condition-based maintenance of power transformer, preliminary exploration the online monitoring and repair methods. Above-mentioned researches were restricted to one or several troubleshooting methods, but it’s lack of research on comprehensive and three-dimensional hierarchy application, unrealized high degree of unity echelon management and integrated scheduling, and it’s lack of energy efficiency data comprehensive assessment system and dynamic optimization integration strategies.

The paper summarizes the five power transformer fault types according to the site firstly, then divided power transformer fault into three stages from the time dimension. Then set a criterion of
power transformer running state using DGA conventional analysis and infrared diagnostics. Finally, according to the demand of power transformer fault diagnosis, built power transformer fault tree by pressing dendritic stepwise refinement from overall to section.

2. Fault types and stages

2.1. The structure of power transformers
Power transformer can be divided into the body and attachments from the structure.

(1) Body
The body of power transformer can be divided into three parts: 1) transformer body, includes a core, a coil and a clamping device; 2) tank, to place the body and transformer oil; 3) transformer oil, for the insulation, cooling, corrosion of body.

(2) Attachments
The attachments of power transformer mainly includes: 1) transformer oil pillow; 2) cooling system; 3) casing; 4) on-load tap-changer; 5) testing instrument; 6) body guard.

2.2. Fault types of power transformers
The main fault types of power transformer can be divided into ten categories according to different parts, such as core fault, casing fault, cooling system fault, load fault, winding fault, insulation fault, radiator fault, tap changer fault, seal fault, and other fault.

There are five main fault as follows:

(1) Lead fault
Lead is the wire to connect the packaging body and external of power transformer. Lead fault is affected by welding quality, and it can be subdivided into poor contact, open circuit and short circuit. Lead phase short circuit may further lead to a winding short circuit. The harm of poor contact and ground short circuit is relatively small.

(2) Winding fault
Winding is the main component of power transformer. Winding fault is mainly in the terminal, longitudinal insulation and coils. It includes winding loose, open circuit, short circuit, and deformation.

(3) Insulation fault
Insulation system mainly includes insulating paper, board, transformer oil and insulating member. Insulation fault is the fault of insulation system caused by insulating paper thin and brittle.

(4) Tap changer fault
Tap changer can be divided into on-load tap-changer and off-circuit tap-changer. It can change the number of turns of the high voltage coil. On-load tap-changer is the high incidence site of power transformer fault because of its run regulating device and the switching operation is very frequent.

(5) Seal fault
The consequence of seal fault is more serious. The main reasons of seal fault are bushing rupture, pump seal bad, welding bad and seal aging.

2.3. Fault stages of power transformers
With the increasing of use time, the fault stages of power transformer can be divided into early fault period, accidental fault period, loss fault period.

(1) Early fault period
Early fault period is the 1-3 years after power transformer was put into use. The fault rate is relatively high at this stage. The fault rate is lower with the operation time is longer.

(2) Accidental fault period
Accidental fault period is the remaining useful life after early fault period. The fault rate is steady at this stage. Fault doesn’t occur under normal circumstances unless the accident occurred.

(3) Loss fault period
Loss fault period is on the eve of retirement. The fault rate has a substantial increase with the operation time is longer.

3. Running state criterion

3.1. DGA routine analytical methods

Currently, most power transformers are still oil-immersed transformers. The main method of operation condition monitoring of oil-immersed transformers is dissolved gas analysis (DGA). The data sampling accuracy is high, the efficiency is high, and the timeliness is good.

Three ratio method and characteristic gas method are the most common methods. Artificial intelligence analysis methods such as fuzzy diagnosis, artificial neural network and expert diagnostic system have been applied gradually.

There are two methods of fault diagnosis of power transformer.

(1) The normal value of the dissolved gas in oil is standard, determinate dissolved gas content in power transformer oil. The normal value of the dissolved gas in oil is as shown in table I. The limit values of hydrogen and hydrocarbon gas content are listed in table I. The dissolved gas in oil should be less than this value under normal operating conditions.

| Table I The normal value of the dissolved gas in oil |
|-----------------------------------------------------|
| Gas Composition | H₂ | C₂H₂ | Total Hydrocarbons (C₁+C₂) |
| Normal Limit value (μL/L) | 150 | 1-5 | 150 |

(2) Determinate gas production rate of power transformer. The gas production rate of power transformer is affected by factors such as fault location, fault energy consumption and temperature. Specific determination methods are shown as table II.

| Table II determination methods of gas production rate |
|-------------------------------------------------------|
| Serial Number | Phenomenon | Conclusion              |
| 1             | a<b, c<d   | Normal                  |
| 2             | b<a<3b, c<d | Slight Fault            |
| 3             | b<a<3b, d<e<2d | Moderate Fault      |
| 4             | a>3b, c>3d | Serious Fault           |

a: the absolute value of total hydrocarbons actual content;
b: the normal value of total hydrocarbons content;
c: the actual gas production rate of total hydrocarbons;
d: the normal value of the gas production rate of total hydrocarbons

3.2. Infrared diagnosis methods

Fault infrared diagnosis technology is a emerging technology area. It used modern infrared technology and artificial intelligence technology to solve the problem of equipment diagnosis in modern equipment management system engineering.

Infrared diagnosis technology can depth analysis of the heat distribution of power transformer fault. It’s easy to clear the surface temperature of the heater case. The analysis of temperature changes very accurate. In addition, its data source is wide, the automation degree is high, and it’s stable and reliable. Thus, infrared diagnosis technology is an important technology of fault diagnosis of temperature rise type of power transformer.
4. Fault tree diagnosis

4.1. Fault tree of power transformer

Fault tree analysis (FTA) is an important method of fault diagnosis of power transformer. It is a special logical causal diagram, and it analysis from the whole to the local level like a inverted tree.

The main purpose to construct fault tree of power transformer is analysis the proportion of each part step by step by expression such as event code and logic gate symbols. And then the technology or management tools can be put forward to management fault hidden troubles.

Fault tree of power transformer includes 8 subtrees such as “current carrying system”, “core”, “insulating oil”, etc. The symbols of fault tree of power transformer are shown as table III.

Table III The symbols of fault tree of power transformer

| Serial Number | Name            | Symbols | Explanation                                           |
|---------------|-----------------|---------|------------------------------------------------------|
| 1             | Bottom Event    | ![Symbol](symbol1) | Unable to continue decomposition of the underlying event |
| 2             | Top Event       | ![Symbol](symbol2) | Event at the top of the fault tree                   |
| 3             | Interme-diante Event | ![Symbol](symbol3) | Event between bottom event and top event            |

| Serial Number | Name         | Symbols | Explanation                                           |
|---------------|--------------|---------|------------------------------------------------------|
| 1             | Or Gate      | ![Symbol](symbol4) | Multiple input events, if one input event or multiple input events occur, output event occur |
| 2             | And Gate     | ![Symbol](symbol5) | Multiple input events, all input events occur at the same time, output event occur |

The subtrees such as “cooling system”, “current carrying system” and “insulation damage” are constructed as follow figures:

![Fig. 1. Cooling system fault tree](image.png)
Current carrying fault

Fig. 2. Current carrying system fault tree

Insulation damage fault tree

Fig. 3. Insulation damage fault tree

Cooling system fault tree draft according to fault tree files

Fig. 4. Cooling system fault tree draft according to fault tree files
4.2. Analysis modules of fault tree
Analysis modules of fault tree of power transformer include probability file module, correction module, qualitative and quantitative analysis module, reliability analysis module and display module.

(1) Probability file module
Probability file module includes some information such as fault name, fault probability and fault code. It calculated the probability of bottom events through annual fault rate, probability value, operation time, etc.

(2) Correction module
Correction module mainly used to modify annual fault rate and operation time.

(3) Qualitative and quantitative analysis module
Qualitative and quantitative analysis module mainly carry out qualitative and quantitative analysis of subtrees.

(4) Reliability analysis module
Reliability analysis module combined analysis results of subtrees before analysis the entire fault tree.

(5) Display module
Display module is used to intuitive display the results of fault diagnosis of power transformer. It can display the logical relationship between events of fault tree comprehensively and clearly.

5. Conclusion
With the development of economy and society, people are getting more and more high demand for power supply. Power transformer is an important equipment of power plants and substations. Simultaneously, it’s an important hub of send transmission substation link of power system. The performance quality and operating condition of power transformer direct impact the reliability and stability of power system. Therefore, the importance of fault diagnosis of power transformer is becoming increasingly prominent.

The fault types of power transformer are relatively complicated. Summary the fault types of power transformer is an important reference to design, manufacture and inspection power transformers. This paper summed up five fault types of power transformer firstly. Then divided fault stages of power transformer into three stages from time dimension. Afterwards, set running state criterion of power transformer by DGA routine analytical methods and infrared diagnosis methods. Finally, constructed fault tree of power transformer by the general to the section by stepwise refinement of dendritic tree according to the needs of power transformer fault diagnosis. The fault tree of power transformer provides an important basis for state monitoring and fault diagnosis of power transformer.

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