Research review on Transformer Fire Protection Technology

Wei Chen1, *, Sheng Hu1a, Lisong Tang2b, YangLing Ou1c, Jianhong Lv1d, Xiaowen Wu1e, Ling Lu1f and Jiwen Peng1g

1State Grid Hunan Electric Power Corporation Research Institute, Changsha, China
2State Grid Hunan Electric Power Company Limited Economic & Technical Research Institute, Changsha, China
*Corresponding author e-mail: chenw69@163.com, ahhusheng@163.com, 466919416@qq.com, 309087135@qq.com, 517144347@qq.com, wxwwhu@163.com, luling11@mails.ucas.ac.cn, 418471994@qq.com.

Abstract. Transformer is the core equipment in power plant and substation. Its safety problem directly affects the normal operation of the whole power plant or substation. In the event of fire, it not only affects the normal operation and system load of the system, but also affects the normal operation and load of the system. In this paper, the main causes of transformer fire, fire pre-warning technology and fire extinguishing technology are introduced comprehensively. A on-line detection fire warning technology without blackout is proposed by analyzing transformer operating noise. Finally, the substation fire protection technology from the aspect of civil engineering design is introduced briefly.

1. Introduction
With the continuous development of social economy, people's electricity consumption is increasing, the role of transformer is increasing, and the fire caused by transformer is increasing day by day. Transformer is the core equipment in power plant and substation. Its safety problem directly affects the normal operation of the whole power plant or substation. In the event of fire, it not only affects the normal operation and system load of the system, but also affects the normal operation and load of the system. It also poses a serious threat to the safety of the surrounding building facilities and personnel. Especially, it is more and more important to prevent transformer fire effectively because it is more dangerous and difficult to fight the large transformer fire. In this paper, the main causes of transformer fire, fire warning technology and transformer fire extinguishing technology are introduced comprehensively, and the on-line detection fire warning technology without blackout is put forward by analyzing transformer operating noise. Finally, from the aspect of civil engineering design, the research of substation fire protection technology is introduced briefly.

2. The causes of Transformer Fire
As the most widely used transformer, oil-immersed power transformer consists of iron core, coil, oil tank, radiator, insulation casing, explosion-proof pipe (safe airway), oil meter, moisture absorber and so on. Its internal insulation gaskets and supports, mostly adopt paper, cotton yarn, cloth, wood and other organic combustible substances, full of insulating oil at the same time. So the transformer is combustible and the main causes of transformer fire are as follows:
(1) When the transformer is overloaded for a long time, it will cause coil heating and gradually aging insulation, causing inter-turn short circuit, interphase short circuit or short circuit to the ground, and then cause transformer fire;

(2) Bad connection happen between transformer winding or connection point leading to the high, voltage porcelain or the contact point of voltage regulating switch, will results in local overheating, and then destroys the internal insulation of the transformer;

(3) If the load of transformer is short-circuit, and the protection system fails or the setting value is too large at same time, the internal temperature of transformer will rise, which will burn the transformer and cause fire;

(4) Due to the poor neutral grounding, the contact resistance is larger, when the three-phase load is unbalanced, there is a large current on the zero line, which leads to the high temperature of the contact site and the ignition of combustible material;

(5) Due to the oil leakage of the oil tank or casing, the formation of surface fouling will burning in open fire;

(6) When the transformer power supply is introduced by overhead wire, it is easy to be attacked by the overvoltage caused by lightning and break down the insulation of the transformer and cause the fire.

3. Transformer fire pre-warning technology

When an electrical failure occurs in the transformer, the main characteristic is the rapid rise of the internal temperature, and the increase of the outer surface temperature can be detected by temperature-sensitive fire detectors. Considering the accurately and sensitively, the fire detector suitable for transformer needs to meet the following two requirements: a) The large-scale oil-immersed power transformer is usually installed outdoors. The influence of environmental changes such as rain, snow, salt mist and humidity on the detection effect should be taken into account in the detection and alarm equipment; b) Transformer is a kind of high-voltage equipment, and it continuously radiates strong electromagnetic interference signal into space. Therefore, fire detection and alarm equipment used to protect transformer should have strong anti-electromagnetic interference capability.

The fire detector, which is actually applied to the fire alarm of transformer, can be divided into four types: point-type temperature-sensing detector, flame detector, cable-type temperature-sensing detector and smoke-sensing detector.

3.1. Point temperature sensing fire detector

The point-type temperature sensing fire detector is an early fire detection technology. It uses a special semiconductor thermistor (CTR) as the sensing element with a very high resistance value at normal temperature. The resistance will decrease slowly with the increase of ambient temperature. When it achieve the setting temperature, the critical resistance will decrease rapidly, and the current of the signal will increase rapidly.

In the application of transformer, the point-type temperature sensing fire detector is installed in the surrounding space of the oil-immersed power transformer, and the probe is placed at a 45° angle towards the transformer body. At present, the spot-type temperature sensing fire detector is more in domestic manufacturers, the product technology is mature, the social cognition is high, the cost is low and it is still used in the transformer fire pre-warning system. However, the weak anti-electromagnetic interference, easy to be disturbed by external environment limit its use.

3.2. Flame fire detector

The flame detector can realize the fire alarm by detecting the infrared or ultraviolet light waves emitted by the flame. When a substance burns, it produces smoke and heat, as well as light radiation. Flame detector is a kind of fire detector, which is used to respond to the light characteristics of fire, that is, to detect the light intensity of flame combustion and the flicker frequency of flame. Infrared flame detector is characterized by long detection distance, good environmental adaptability and small
interference by electromagnetic radiation, but it also has some disadvantages such as easy to be polluted and high cost.

3.3. Cable-type temperature-sensing detector
Cable-type linear temperature sensing fire detector is a widely used fire alarm detection method in electric power grid in recent ten years. Its working principle is that when the temperature rises to the rated operating temperature, the performance of the thermosensitive material changes, which makes the infinite resistance value between the steel wires jump under normal conditions, approaching short circuit, and the ordinary weak current increases remarkably. The installation of cable-type thermal detector is usually tightly wound around the transformer body, spiral or layered laying mode is not affected by the voltage level of the transformer (but the shielding line must be well grounded). The installation mode also determines the ambient temperature, and the change of wind speed has little effect on it. At the same time, because this type of detector has strong anti-electromagnetic interference ability, waterproof, good moisture-proof performance.

3.4. Smoke-sensing fire detector
Smoke-sensing fire detector is manufactured by special structure photoelectric sensor. It has the characteristics of high sensitivity, stable and reliable, low power consumption, beautiful and durable, easy to use and so on. The circuit and the power supply can self-check and carry on the analog alarm test. In the early stage of the fire, due to the low temperature, substances are mostly in the smoldering stage, and the transformer will not burn quickly, which will produce some visible or invisible smoke. When the smoke appears, the smoke detector will receive the signal from the smoke, enhance its conductive resistance, change the current through which the receiving element flows, and finally make the detector sound an alarm.

All of the above fire detectors alarm works only after the fire occurs. So how to realize the fire warning by detecting the operation parameters of transformer before the fire has more practical significance. For example, the temperature rise, operation noise, insulation oil analysis, overloading capacity and voltage allowable fluctuation value of transformer can be analyzed and early-warning can be carried out.

Through the analysis of transformer operation noise, the on-line fire warning without blackout can be realized. Transformer in normal work will emit a uniform "buzzing" sound, if the transformer or external circuit failure, will appear abnormal sound, witch may be caused by core piercing bolts or nuts and other internal structure loose; There may be breakdown between windings and iron cores; a loud and heavy "buzzing" may be caused by overloading of the transformer. Special attention should be paid to the fact that when the winding is short-circuit between turns, the winding at the short-circuit will heat up and cause the transformer oil to boil and make a "purr" sound, and then it should be overhauled and overhauled immediately. Therefore, to strengthen the sound monitoring in transformer operation, the equipment defects can be found in time.

4. Transformer fire extinguishing technology
Transformer fire extinguishing systems mainly includes water spray fire extinguishing system, oil-discharge and nitrogen-injection fire extinguishing system and gas fire extinguishing system.

4.1. Water spray fire extinguishing system
Water spray fire extinguishing system is one of the earliest fixed fire extinguishing systems used in transformer fire fighting. It mainly consists of water source, water supply equipment, pipe, raindrop valve group, filter and water mist sprinkler. The fire extinguishing mechanism is that the small water mist droplets are sprayed directly to the burning material surface by high pressure to produce cooling, suffocating, emulsifying and dilution. The spray water droplets ejected from the water mist nozzle have small particle size and large surface area, and the water droplets emitted from the spray nozzle are small in size and have a large surface area. The combustion surface temperature is rapidly reduced
to below the ignition point and the combustion body is cooled by a large amount of heat taken away by rapid vaporization in the event of fire.

The technology of water spray fire extinguishing system is mature for its high efficiency, and it has been widely used both at home and abroad. But its system is complicated, including not only a set of devices, such as raindrop valve group, pipe and bracket, atomization nozzle, detector and linkage control plate, but also a supporting fire water supply system such as water pool, water pump, pipe network and so on, which covers a large area and costs a high cost.

4.2. Oil-discharge and nitrogen-injection fire extinguishing system

The principle of the system is that the insulation oil in the oil tank will decompose and produce a large number of flammable gases such as methane and hydrogen when the transformer internal fault occurs. These gases touch the gas relay and send out certain dangerous signals. The internal fault of transformer can also increase the temperature of the internal insulation oil, and the temperature sensor in the internal system will receive the signal and send a certain signal to the computer. When the fire protection department receives the dangerous signal generated in the transformer, it starts the oil discharge and nitrogen injection system to discharge the insulating oil inside the transformer and reduces the internal pressure. At the same time, the shut-off valve of the oil-discharging and nitrogen-filling system automatically closes. Stop the operation of oil supply in transformer, reduce the quantity of oil in transformer greatly, and prevent the transformer from causing more serious harm. After a short period of time, the nitrogen release valve is opened and nitrogen gradually enters from the fuel tank to isolate the insulating oil from the air, which fundamentally solves the problem of combustion. The whole system is simple in structure and convenient in operation and maintenance.

4.3. Gas fire extinguishing system

The gas fire extinguishing system is mainly used in the environment which is not suitable for other fire extinguishing systems such as water extinguishing system. In the gas fire extinguishing system, the gas used is carbon dioxide, heptafluoropropane, fumigation and other gas materials. Because of the high requirement of using gas fire extinguishing system, it will cause certain influence to the natural environment and damage to transformer after the fire extinguishing work. At the same time, the cost of this kind of system is relatively expensive and the cost is high. This fire extinguishing system is rarely used in transformer fire fighting.

5. Fire Protection considerations in Substation Civil Design

Substation fire protection design mainly includes buildings, electrical equipment, distribution site, cable, unattended substation and other aspects of fire protection design.

In the aspect of fire protection design for buildings, due to the different functions in the substation, fire protection measures should be targeted and suitable. When the building spacing is determined and the site itself is limited, firewalls should be strengthened. The fire resistance grade of buildings must meet the standard, especially the fire resistance limit of building components to meet the needs of actual fire protection grade. The wall should be composed of self-extinguishing materials and the roof should be composed of non-combustible materials. In order to reduce the casualties and losses caused by fire accidents, the design of fire evacuation passage must be strengthened.

In the aspect of fire protection design for electrical equipment, it is necessary to choose a suitable type of fire extinguisher in substations. In particular, many electrical equipment has the characteristics of flammability and explosion, it is necessary to strengthen the setting of explosion-proof partition wall. The explosion-proof products should be used in the ventilation equipment, special equipment set, corridor socket and switch settings. Especially for the transformers, as the main basic equipment in the whole station, its fire protection grade requirement must be improved. Civil designers must be fully aware of the safety of the distance between the transformer and the building and scientifically install chemical fire extinguishers in the process of setting up the fireproof partition.
In the aspect of fire protection design for the distribution site, the main research areas are the distribution site outside the house, which should be designed as a circular road. If the excellent oil filling equipment outside the house is more than 1 t, the oil storage pit must be set up to pour the oil into the safe outlet. Fireproof sandbox is a common method in the distribution site to control the fire when the fire occurs. If the sandbox setting is unreasonable, it will not only make the yellow sand stack scattered, but also reduce its fire protection performance. Therefore, in the process of setting up the sand box, rain water should be strictly prevented from entering the sand box above, and the water should be infiltrated under the sand box.

In the process of cable fire protection design, because of the high frequency of cable fire, the cable has been set up both indoors and outdoors. Due to its wide range of distribution, it is not realistic to adopt fixed fire extinguishing equipment for the cable fire protection design. This requires separation and flame retardancy in the process of cable fire protection design. Therefore, the common measures are to set partition or add yellow sand in the bifurcation line of cable trench to achieve the purpose of flame-retardant and fire-retardant. When the length of the cable is longer, it should be blocked by a piecewise method, and the interface of the cable is the focus of fire prevention, so the entrance should use fireproof materials to block the pores, so as to better prevent the spread of fire to the building. And the indoor floor around the cable should be coated with fireproof material.

In the process of fire protection design of unattended substation, it is necessary to ensure that the fire fighting equipment prepared is in line with the overall scale of the substation. To make the best use of the equipment as far as possible, and put all the fire prevention equipment reasonably, so that the fire protection equipment can be used at the first time after the fire occurs. The fire prevention system should be perfected continuously, the fire prediction and monitoring should be strengthened in time, and the monitoring personnel should be notified as soon as the fire happens, especially the application of infrared monitoring technology. As a result, the temperature of the running equipment and the joint is detected to avoid the equipment being burned out and to prevent the occurrence of the fire accident at the same time.

6. Conclusion
This paper analyzes the reasons for the hidden danger of transformer, and discusses the fire detection technology and fire extinguishing technology of transformer from several aspects. This paper discusses how to realize the fire warning by detecting the running parameters of transformer before the fire occurs. For example, the temperature rise, operation noise, insulation oil analysis, overloading capacity and voltage allowable fluctuation value of transformer can be analyzed and early-warning can be carried out. Finally, from the angle of civil engineering design, the research of substation fire protection technology is introduced briefly.

References
[1] Chilworth Technolog Plainsboro, Process Safety Test Results and Interpretation [R]. Report Number R /5246/0105/N K, 2006.
[2] National Fire Prevention Association, NFPA 850. Recommended Practice for Fire Protection for Electric Generating Plants and High Voltage Direct Current Converter Stations [S].
[3] Hydroelectric Research and Technical Services Group, Transformer Fire Protection[R]. Denver, Colorado: U. S. Department of the Interior, Bureau of Reclamation, 2005.
[4] Chen Songping, XIANG Fangcheng, WAN Li, Research on new technology of transformer fire detection, Fire Science and Technology, June 2018, Vol 37, No. 6.
[5] Zhao Jiajing, Liu Yancheng, Yu Ying, Du Wenjie, Design of Electric Fire and Early-warning Fire Prevention System Used in the Transformer Substation. Proceeding of 2006 Chinese Control and Decision Conference.
[6] Ren Chang-xing, LI Jin, ZHANG Wang, Fire safety analysis on the high burning point insulating oil of transformers, Fire Science and Technology, November 2009, Vol 28, No. 11.
[7] Li Liang, Design of automatic fire alarm and linkage control for oil-immersed transformer
[J]. Architectural electrical, 2014. 03(07):36.