

# The Fault Current of Oil-immersed Power Transformer Draws Abnormal Gases

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**Abstract**—Oil-immersed power transformers play an important role in power system. To increase the efficiency and reduce the operating temperature, a large amount of insulating oil needs to be injected. It generates a very high temperature because after the fault current and thus escapes the flammable gases - hydrogen ( $H_2$ ), methane ( $C_2H_4$ ), acetylene ( $C_2H_2$ ), ethylene ( $CH_4$ ), ethane ( $C_2H_6$ ), Carbon monoxide ( $CO$ ). If the high temperature continues to reach the ignition point, it will cause a combustion and explosion. Therefore, in the initial stage of high-temperature generation of the transformer, it is necessary to properly and quickly isolate (break) the fault point by protecting equipment to save the power from being high temperature. The fault current of transformer calculated being depends on the positive, negative, zero sequence network impedance of the system and each device that the results are been calculation and conversion, and the capacity value of the combustible gas is converted by the Joule formula calculation. After the accident, the fault point should be completed isolation task in about 1/10 seconds in a very short time. In order to avoid the accident spread and the system will stabilize to supply the power.

**Index Terms**—Oil-immersed Power Transformer, Per-unit System, Fault Current, Protect Relay.

## 1 INTRODUCTION

The aim of this paper is to introduce the flammable gases what creates from the insulation oil of oil-immersed transformer when it was been impacted of the fault current which was been provided from power system. These gases of flammable will increase the internal temperature of the transformer to the ignition point ( $140\text{ }^\circ\text{C}$ ) when the fault current of power system still continues to supply, so that the time of reaching the ignition point must be accurately calculated. After the time points was been taken as a set value of the protection relay by the professional staff to planning on electric power. It is so accurately calculated the time of the energy generation and how account of abnormal gases which were been yielded from the fault current, that then taking it to plan what how to set each protection relay of operating time on the power system. In order to confirm that the action time point of the protection relay set by each equipment is a reasonable safety of operating and accurately turned off the fault point by the protection relay right time and automatically. The fault current of oil-immersed transformer and the quantity of flammable gases were been calculated with the reference of relevant literature data in concise manner, and those different unit converted which was been introduced in this article. Then the article introduces the importance of setting time of operation for the automatic protection relay. At the end of the article, the maintenance personne necessary noticed to implement

each maintenance work which work must to plane and carry on from the annual to monthly practical. So that can avoid human negligence and causing equipment lack of maintenance and repair leads to damage to the equipment, resulting in power system unstable and the economy and people's livelihood affecting.

## 2 BACKGROUND

According to the procurement specifications of the oil-immersed power transformer of Taiwan Power Company, the oil-immersed transformer inter body needs to be able to withstand the internal pressure of  $1.05\text{kg/cm}^2$ , and the operating pressure of the pressure-relief relay is  $0.7\text{kg/cm}^2$ . It needs automatic release and automatic reset, and the sudden pressure relay is operated, the pressure rise rate should be limited less than  $0.035\text{ kg/cm}^2/\text{sec}$ .

In any event of a failure inside the oil-immersed power transformer will be drawn six flammable gases because the decomposition of the arc insulating oil from insulation oil. Those gases will rise rapidly to releas from the internal of transformer body, at this time; the pressure-relief relay and the sudden pressure relay are used as the main protection elements to drive the isolation action. However, no matter what kind of protection relay action, the mechanism link delay time for the circuit breaker trip must be added into as execution time so that was been called operating tripping time, which needs to less than 1/10 second. The pressure of abnormal gases must be been released at under  $1.05\text{kg/cm}^2$  of internal

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pressure of the transformer before, so can be effective and free from explosion fire disasters.

The abnormal gases or pressure of disturbance were been generated from inside the transformer body, they were been divided into two kinds - locality and mobility both by propagation of the sonic speed in internal body. The inside of the body can burden to a transient pressure of up to 13 bar (1 bar equals 1.019716 kg/cm<sup>2</sup>). The dynamic pressure is formed (about 1/10 second), after the pressure will be evenly distributed throughout the body. But the transformer body is only allowed to burden a pressure of 1.05kg/cm<sup>2</sup>. Therefore, after the pressure stroke, the protection relay is necessary to complete the fault point isolation within the above time (1/10 second) from power system; otherwise the body may be broken [1]. As for in term of the per-unit system (pu) is a tool for calculating the impedance value of any equipment on power system. To select the appropriate reference value as basic reference point so that it can simplify to calculate the equivalent for variety of different voltage level on power system. It can be applied to avoid calculation errors.

### 3 INSULATION OIL IN INTERNAL TRANSFORMER

#### 3.1 INSULATION OIL

The oil-immersed power transformer is equipped with a large amount of insulating oil (depending on the capacity of the equipment). In addition to providing cooling and heat dissipation and increasing the power supply capacity, it has a special function to detect the operation of various parts inside the transformer body by gas analysis in the oil.

TABLE 1  
ANSI/IEEE C57.104 Gases Standard unit: ppm

Gas	Quantity	Property	Gas	Quantity	Property
H <sub>2</sub>	> 1801	Danger	CH <sub>4</sub>	> 1001	Danger
	> 701	Abnormal		> 401	Abnormal
	> 101	Notice		> 121	Notice
	< 100	Normal		< 120	Normal
C <sub>2</sub> H <sub>6</sub>	> 151	Danger	C <sub>2</sub> H <sub>4</sub>	> 201	Danger
	> 101	Abnormal		> 101	Abnormal
	> 66	Notice		> 51	Notice
	< 65	Normal		< 50	Normal
C <sub>2</sub> H <sub>2</sub>	> 35	Danger	CO	> 1400	Danger
	> 10	Abnormal		> 571	Abnormal
	> 2	Notice		> 351	Notice
	< 1	Normal		< 350	Normal

When internal abnormal of oil-immersed transformer occurs during running or the insulation material deteriorates to generate heat, this abnormal matter will penetrate into the interior structure of the insulating oil. Having a period time is taken the sample of the insulation oil to detect so that can obtain the result of analysis from the insulation oil by instrument of thermal decomposition chromatography (ASTM D3612). When the insulating oil is running to heat or high temperature (100°C) over, it will decompose combustible gases and cause deterioration of equipment insulation; the concentration specifications combustible gases are shown in Table 1. Therefore, the maintenance personnel necessary take the sample of the transformer insulating oil to the Taipower Comprehensive Research Institute every year and according to the manufacturer's maintenance manual and ANSI/IEEE C57.104 standard to check whether there are flammable gases inside the transformer body.

#### 3.2 RELATIONSHIP WITH COMBUSTIBLE GASES AND TEMPERATURE

The load current had made the contact point with the conduct wire to heat up, causing the insulation material to deteriorate or causing partial discharge or arcing or sparking etc., those abnormal phenomenon were caused from the inadvertent handling during it was been installed. Under the electromagnetic stress of long-term running, the hydrocarbon molecules will decompose active hydrogen and hydrocarbon molecules from the internal structure of the insulating oil and then chemically react to form hydrogen, methane, acetylene, ethylene and ethane. Each different combustible gas is decomposed from the insulating oil depending on the degree of internal temperature rise of the transformer. These gases, such as hydrogen (H<sub>2</sub>) and methane (CH<sub>4</sub>), begin to decompose and emit from the insulating oil at around 150 °C. However, ethylene (CH<sub>4</sub>) starts to emit form at around 160 °C and ends at 1,200 °C. The ethane (C<sub>2</sub>H<sub>6</sub>) begins to emit at around 250 °C and ends at about 1,200 °C, methane (C<sub>2</sub>H<sub>4</sub>) begins to emit at 350 °C, and acetylene (C<sub>2</sub>H<sub>2</sub>) begins to emit at 500 °C. The relationship between the combustible of each gas and the temperature were as shown in Fig 1.

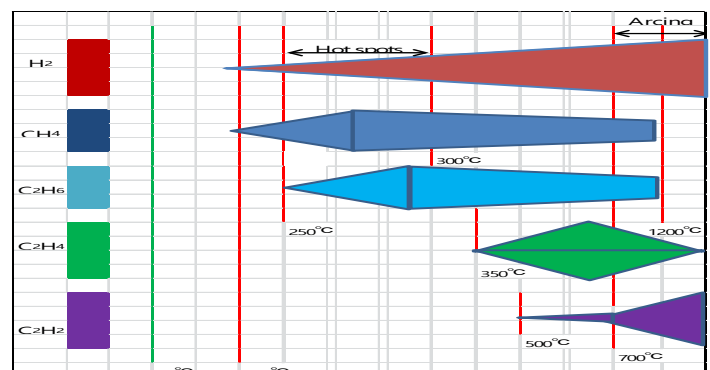


Fig 1

Knowing that the temperature is closely related to the running of the transformer, so the manufacturers or power companies that are based on the safety of the equipment. The oil-immersed transformer is recommended to run at temperatures below 65 °C and is still normal and avoids over 90 °C. If the running temperature were high over normal due to being overload, the insulating oil is aging and the insulation is reduced. However, when the internal fault current occurs in transformer, a high temperature will be generating by the insulating oil. If the fault current is still continuing as the temperature is up to ignition point (140 °C), the spark of being generate form fault current can be ignites the combustible gases and explode. [2]

### 3.3 THE FAULT CURRENT CALCULATION

Transformer's internal fault (short circuit) current calculation must start from the short-circuit capacity of the system power supply, but the basic information of any equipment and the equipment's parameters and short-circuit capacity values of system those data were provided by manufacturers and Taiwan Power Company. Because of the space limitations, some theories are not repeated here. For more details, please refer to the reference data [3]. This article only mentions the capacity and voltage level of the transformer and the reactance ratio, as shown in Table 2.

TABLE 2  
 THE PARAMETERS DATA OF TRANSFORMER

Voltage Level (kV)	Capacity (KVA)	Reactance Ratio (%)	Grounding Method
69	15	7.5	Direction

$$Z_{ps} = (69 \text{ kV} * 69 \text{ kV}) / 15 \text{ MVA} = 316\Omega$$

$$Z_{base} = (69 \text{ kV} * 69 \text{ kV}) / 100 \text{ MVA} = 47.6\Omega$$

$$Z_{(pu)} = Z_{ps} / Z_{base} = 316\Omega / 47.6\Omega = 6.64 \text{ pu}$$

$$Z_{(pu)} = 6.64 \text{ pu} * 7.5 = 0.498 \text{ pu}$$

$$I_{base} = 100 \text{ MVA} / (1.73 * 69 \text{ kV}) = 836.7 \text{ A}$$

$$I_{3\phi f} = (1 / Z_{(pu)}) * I_{base} = 1 / 0.498 * 836.7 \text{ A} = 1,680 \text{ A}$$

From the calculation of the transformer's internal fault current, there will be 1,680 A of fault current supplied by the power system through the fault point.

### 3.4 TRANSFORMER'S PROTECTIVE EQUIPMENT

Because of Oil-immersed power transformer plays an important role in power system, so that has two types of protection equipment - mechanical and electrical been installed on to protect, the protection relays were not only quality but also accuracy than others devices.

The protection relay of the electrical type includes Differential, Over-current, and Distance Measuring. As for The me-

chanical type are Buchholz Relay, Pressure Relief Device, Sudden Pressure Relay, and Gas in oil Generation Monitoring Devices, etc. When a fault occurred in oil-immersed power transformer inside, the protection relay is automatically judged and accurately opened of the circuit breakers which were been installed on both sides of the transformer within 1/10 second, to cut the fault point that allow other equipment to supply normal.

### 3.5 FAULT CURRENT DRAWS ABNORMAL GASES

The dynamic pressure of the oil-immersed transformer inside body is caused by the fault current, as for the energy was calculated method as Equation (1) and the changing of related unit converted as described below.

$$1 \text{ Joule} = 0.24 * I^2 * R * t \tag{1}$$

$$337,333 \text{ Joule} = 0.24 * (1,680)^2 * 0.498 * t$$

$$1 \text{ Calore} = 4.18 \text{ Joule}$$

$$1,410,051 \text{ Calore} = 4.18 \text{ Joule} * 337,333 \text{ Joule}$$

$$1 \text{ Joule} = 0.0000102 \text{ kg/cm}^2$$

$$3.44 \text{ kg/cm}^2 = 0.000102 \text{ kg/cm}^2 * 337,333 \text{ Joule}$$

$$337,333 \text{ Joule} = 0.076 \text{ Cubic meter} = 76 \text{ Litre (combustible gases)}$$

From the above formula, as the result of the fault current of the three-phase internal fault of the transformer is 1,680 A and the abnormal energy is 337,333 joules. Those energy of abnormal gases is been converted into the quantity of combustible gases is 0.076 m<sup>3</sup> (76 liters), the pressure is 3.44 kg/cm<sup>2</sup>.

If it is unable to quickly isolate the fault point and released the combustible gases and pressure within 1/10 seconds after the fault current occurred, when the temperature reach up to 140 °C, the transformer will ignite and explode.

### 4 CONCLUSION

From the above information and calculation results, it is known that the oil-immersed power transformer in running stage should be regularly taken from the insulating oil sample for inspection according to the manufacturer's manual. So that to understand what is inside of body whether latently abnormal point. This article took the data of an oil-immersed transformer (15MVA) as an example. The result of calculus current of the formula is 1,680 A, which generates 337,333 joules of energy, which is converted into 0.076 m<sup>3</sup> (76 liters) of combustible gases and its pressure of 3.44 kg/cm<sup>2</sup>. After checking with the data of the literature, it can be withstand a short period of pressure (13.256308kg/cm<sup>2</sup>). However, if the

combustible gases and the abnormal pressure cannot accurately isolate the fault point within 1/10 seconds, the result will ignite and explode of the oil-immersed transformer, so that even affect the power supply ability and the normal equipment.

Therefore, maintenance personnel must implement the maintenance work plan for the year and month regularly, especially the inspection of the auxiliary equipment of the transformers to ensure the safe running of the equipment.

In addition, the setting of the operation time of the electrical protection relay must be determined by the professional person to consider and plan. On-site maintenance personnel are not allowed to change the setting time arbitrarily. If the setting time of the protection relay is changed or the setting time needs to be adjusted, it must be executed or agreed by the professional person of relay.

## REFERENCES

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