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Thermal Securing of Electrical Contacts inside Oil Power Transformers

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***Abstract*—**In the operation of power transformers of 110 kV/MV from substations, these are traveled by fault current resulting from MV line damage. Defect electrical contacts are heated when they are travelled from fault currents. In the case of high temperatures when 135 °C is reached, the electrical insulating oil in the vicinity of the electrical faults comes into contact with these contacts releases gases, and activates the electrical protection. To avoid auto-flammability of electro-insulating oil, we designed a security system thermal of electrical contact defects by pouring fire-resistant polyurethane foam, mastic or mortar fire inside a cardboard electro-insulating cylinder. From practical experience, in the exploitation of power transformers of 110 kV/MT in oil electro-insulating were recorded some passing disconnecting commanded by the gas protection at internal defects. In normal operation and in the optimal load, nominal currents do not require thermal secure contacts inside electrical transformers, contacts are made at the fabrication according to the projects or to repair by solder. In the case of external short circuits close to the substation, the contacts inside electrical transformers, even if they are well made in sizes of Rcontact = 10^{-6} Ω, are subjected to short-circuit currents of the order of 10 kA-20 kA which lead to the dissipation of some significant second-order electric powers, 100 W-400 W, on contact. At some internal or external factors which action on electrical contacts, including electrodynamic efforts at short-circuits, these factors could be degraded over time to values in the range of 10^{-4} Ω to 10^{-5} Ω and if the action time of protection is great, on the order of seconds, power dissipation on electrical contacts achieve high values of 1,0 kW to 40,0 kW. This power leads to strong local heating, hundreds of degrees Celsius and can initiate self-ignition and burning oil in the vicinity of electro-insulating contacts with action the gas relay. Degradation of electrical contacts inside power transformers may not be limited for the duration of their operation. In order to avoid oil burn with gas release near electrical contacts, at short-circuit currents 10 kA-20 kA, we have outlined the following solutions: covering electrical contacts in fireproof materials that would avoid direct burn oil at short circuit and transmission of heat from electrical contact along the conductors with heat dissipation gradually over time, in a large volume of cooling. Flame retardant materials are: polyurethane foam, mastic, cement (concrete). In the normal condition of operation of transformer, insulating of conductors coils is with paper and insulating oil. Ignition points of its two components respectively are approximated: 135 °C heat for oil and 200 ^{0}C for paper. In the case of a faulty electrical contact, about 10^{-3} Ω, at short-circuit; the temperature can reach for a short time, a value of 300 °C-400 °C, which ignite the paper and also the oil. By burning oil, there are local gases that disconnect the power transformer. Securing thermal electrical contacts inside the transformer, in cardboard tube with polyurethane foams, mastik or cement, ensures avoiding gas release and also gas protection working.

***Keywords*—**Power transformer, oil insulatation, electric contacts, gases, gas relay.

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I. Introduction

Electrical resistance of contacts are characterized by two components: the pressure of the contact and -surface of contact. If the contact surface is a fixed component in (1) of electrical resistance [3]:

$$R = \rho \times l/S \tag{1}$$

Contact pressure and the presence of impurities are contributing to the deterioration of the quality in time of electrical contacts. Experience in the operation of transport and distribution installations shows that most faults that occur in electrical contacts are due to the system of operation of the installations, when short circuit currents reach very large values defect. In Table I are a number of theoretical calculations regarding the electric power load on contacts at short circuit. Values were chosen in steps for the resistors and also contact a host of representative values of short-circuit currents [1].

TABLE I
Electric Power Load on Contacts at Short Circuit

	R contact	Isc (kA)	ΔP (kw)	Isc (kA)	ΔP (kw)
1	10^{-2} Ω	1,5 kA	**225**	15 kA	**2250**
2	10^{-3} Ω	1,5 kA	**22,5**	15 kA	**225**
3	10^{-4} Ω	*1,5 kA	* **2,25**	*15 kA	* **22,5**
4	**10^{-5} Ω**	***1,5 kA**	* **0,225**	***15 kA**	* **2,25**
5	**10^{-6} Ω**	***1,5 kA**	* **0,0225**	***15 kA**	* **0,225**
6	10^{-7} Ω	1,5 kA	**0,0022**	15 kA	**0,022**

From Table I, the contacts are made by pressing for rows 1-4. Even if at the moment of pressing the contact, resistance are at value of 10^{-4} Ω - 10^{-5} Ω, meanwhile, contact pressure decreases their values and migrate to the value of 10^{-3} Ω -10^{-2} Ω. For these values for contacts resistance, the power dissipated on the contacts is of the order of hundreds of kW with strong local heating. For rows 5-6 of Table I, the contacts are made by welding with a resistance value of less than 10^{-6} Ω.

Factors which may lead to damage to the electrical contacts inside transformers are mechanical shocks (electrodynamic forces) due to short-circuit.

II. Factors that May Lead to Deterioration of Electrical Contacts Inside Oil Power Transformers

The electrical contacts inside the power transformers both at the manufacturing stage and repairs, to ensure low contact resistance as in beach of 10^{-6}Ω - 10^{-7}Ω [4], the technology is achieved by bonding (welding). Due to its contacts are mounted inside transformers, electrical resistance measurement on each contact at such low values cannot be achieved using current kits approx. 2000 A with measuring the voltage drops.

In fabrication or in repairs power transformers, there is no welding quality control of electrical contacts similar, for example, in aeronautics. In this regard, although an electrical contact made by bonding (welding), video is well done and measurements taken on the continuity of circuits within the values stipulated in the regulations in force, the contact resistance due to bonding (welding) imperfect may be reduced of the order of $10^{-4}\ \Omega$ - $10^{-5}\ \Omega$ with exothermic driven at short-circuit currents.

Other external factors which may cause damage to the electrical contacts inside the transformers are mechanical shocks to which the transformer is subjected to loading onto the repair workshop or factory, during transport and installation of the power station. During operation, at external short circuit, conductors carry current transformer windings of large values of 10 kA-20 kA that are producing significant electrodynamic forces.

Let's consider that the transformer is subjected to external short-circuit current of I = 15 kA for a duration of 1 second tripping of the protection. In this period of time, electrical conductors both in the medium and high voltage inside the transformer attract or repel each other [5] by an electrodynamic force resulting from the short-circuit current, $I1 = I2$, the length of the wires l and the distance d between them are according to (2):

$$F = \frac{\mu I_1 I_2 l}{2\pi d} \tag{2}$$

To simplify the calculations, we consider that the electrodynamic efforts work on one meter of conductor [6] and the distance between two conductors is about 40 centimeters, according to (3) and Fig. 1.

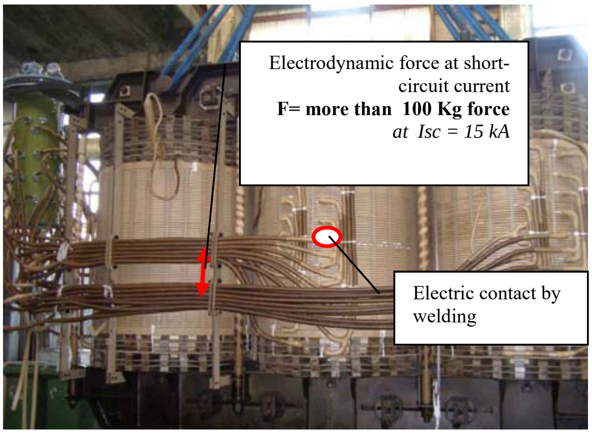

Fig. 1 Electric contacts inside power transformer

$$F = 4\pi 10^{-7} \text{ x } (15 \text{ x } 10^3)^2 / (2\pi \text{ x } 0{,}4) = 112{,}5 \text{ Kgf} \tag{3}$$

Example of damaged electrical contact over time - leading to damage to a power transformer is shown in Fig. 2.

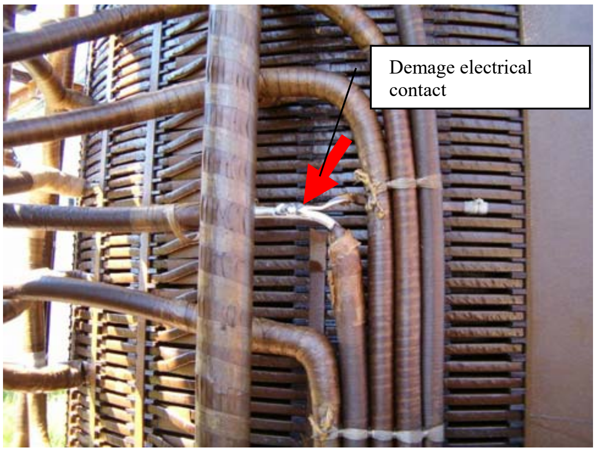

Fig. 2 Example of damage electric contacts inside power transformer

III. Self-Ignition of Oil and Disconnecting Power Transformer by Gas Protection

At operation power transformer in short-circuit, the electrical contacts transit by current of 10 kA-20 kA, conduct at localized heating or hot spots that can cause self-ignition insulating oil and paper insulation. From the technical characteristics, the oil and the electrical insulating paper have the following ignition points, according to Table II.

TABLE II
FLASH POINTS FOR OIL AND PAPER

oil – normal operating	**maximum** 70 ^{0}C
Flash point - oil in use	**minimum *135 ^{0}C***
Flash point – paper	**200 - 275 ^{0}C**
Thermal decomposition of the wood begins at temperatures above 105 °C to 200 °C [4], is greatly accelerated and the maximum amount is 275 °C. A thermal degradation of the wood [2] may occur during prolonged exposure to temperatures below 100 °C. Wooden flashpoint is between 200° C and 275 ° C. In the absence of oxygen, the result is the pyrolysis.	
Degradation of paper	*temperature - min. de 70 ^{0}C*

In the normal operation of the transformer, insulating paper of conductors is soaked with oil [5]. The flashpoints of the two components, oil and paper, are close thermally, about 135 ^{0}C and 200 ^{0}C. In Fig. 1 it is seen that all the electrical contacts are wrapped with insulating paper, but due to its soaking, the oil is in direct connection with the hot electrical contact.

The power dissipated on the damage electric contact in conformity with Fig. 2, is about 22.5 kW, which is equivalent to the simultaneous operation of 22 kitchen hot plates of 1 kW power each and the temperature far exceeds the electrical contact more than 200 ^{0}C. At this temperature, insulating oil burns instantly releasing gas and consequently burns also the insulating paper.

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IV. Thermal Securing of Intrnal Electrical Contacts Inside Oil Power transformers Using Fireproof Materials

Degradation of electrical contacts inside power transformers may not be limited for the duration of their operation. In order to avoid oil burn with gas release near electrical contacts, at short-circuit currents about 10 kA-20 kA, we have outlined the following solutions:

- Covering electrical contacts in fireproof materials that would avoid direct burn oil at short circuit
- Transmission of heat from electrical contact along the conductors with heat dissipation gradually over time, in a large volume of cooling

Flame retardant materials are:

- polyurethane foam

Fig. 3 Fireproof material - polyurethane foam

Fig. 4 Fireproof material – expanded polyurethane foam - mastik

Fig. 5 Fireproof material – mastik

Fig. 6 Fireproof material - cement

From laboratory tests, polyurethane foam, mastik and cement do not react with the oil inside transformer and are chemically stable.

V. Industrial Technologies to Secure Electrical Contacts in Cardboard Tube

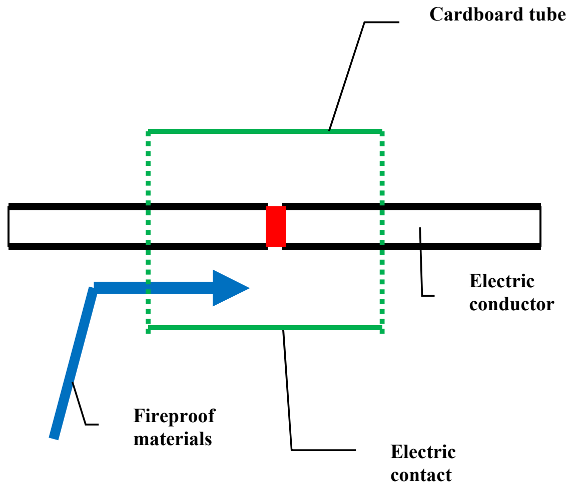

Fig. 7 Secure electrical contacts in cardboard tube – 2 conductors

Depending on the section of conductors and the mounting position of the electrical contacts inside the power transformers, all three flame retardant materials can be used in any combination:

- Fireproof foam adheres well to metal surfaces
- Mastik fills all gaps in insulating cardboard tube easily
- Mortar fire is resistant to temperatures of 1400 °C

Regardless of the fireproof materials used to cover electrical contacts, it is important that they must be isolated and sealed inside cardboard tubes, shown in Fig. 9, to avoid oil penetration in the electric contact area. In this way, there are avoid partial discharge in transformer operation.

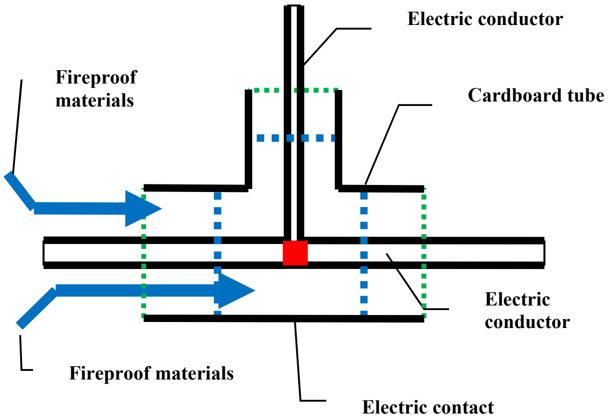

Fig. 8 Secure electrical contacts in cardboard tube – 3 conductors

Fig. 9 Cardboard tubes

VI. Conclusion

Online monitoring of short circuit current transiting the transformers in power stations using SCADA system can give value information about the electrodynamic efforts in coils and also about the vulnerability of electrical contacts.

Securing thermal electrical contacts inside the transformer in cardboard tube with polyurethane foams, mastik or cement ensures avoiding gas release and gas protection working with disconnect electricity feeding at customers.

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