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FIRE PREVENTION METHOD FOR 275KV OIL-FILLED CABLE IN TEPCO

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ABSTRACT

There are many advantages in laying cables in a tunnel in congested area, such as large transmission capacity and easy maintenance. Tunnel installation is selected now more than ever in many countries. But High Voltage Oil-Filled (SCOF) cable fault in a tunnel may cause a fire, and the fire may expand to all the cables inside the tunnel. It is difficult to extinguish tunnel fire due to its low accessibility. One cable fault, however, shall never cause tunnel fire nor affect other circuits. Fire prevention method is crucial.
And the fault caused by negative oil pressure makes larger fault energy, it is important to prevent negative pressure in cables.
This paper describes fire prevention methods developed by Tokyo Electric Power Company (TEPCO), based on many short-circuit tests.

KEYWORDS

SCOF cable, fault, fire prevention, tunnel fire, negative pressure

1. BACKGROUND

As an electric power system becomes larger, the short-circuit current and the ground-fault current in the system become larger. Especially in the EHV power lines (500kV and 275kV in case of TEPCO), those currents tend to become large, because they apply directly grounded system and many power plants are connected. The maximum ground-fault current has increased together with the EHV network expansion in TEPCO.

The increase of the short-circuit current and the ground-fault current cause the following problems.

- Reinforcement of circuit breakers (and other apparatus if necessary)
- Electromagnetic induction to communication wire
- Damage caused by fault current
- Electromagnetic force to the cables

In many cases of EHV underground transmission lines, each cable conductor is shielded in single-phase and only the ground-fault is considered for damage at the fault point.

In the case of SCOF cable fault, fire concern is the greatest. EHV SCOF cable or joint fault in a tunnel may cause a fire, and the fire may expand to all the cables and the ancillary facilities inside the tunnel, because it is difficult to go underground and extinguish the fire.

Therefore, it is necessary to avoid the damage of other circuits and the fire occurrence at the time of a cable fault.

In this paper, the fire prevention method in TEPCO and its background are reported.

2. ASSUMED GROUND-FAULT MODE

2.1.Ground-fault mode

Before discussion about a fire prevention method for SCOF cables, their ground-fault modes were reviewed.
The causes of ground-fault are as follows.

Aging
Long term deterioration by heat and/or electric field may cause insulation deterioration. Contamination or initial defect may trigger the deterioration**.**

Movement of cable core or external stress
Movement of cable core (longitudinal move of the cable core) may make joint insulation paper touch the joint case, and may damage insulation.

Absorption of moisture
External damage or aging of the plastic sheath may cause the degradation of the aluminum sheath, leading to intrusion of water into the cable or absorption of the moisture. It deteriorates insulation.

Negative oil pressure
SCOF cables should be used under positive oil pressure. Used under negative oil pressure, the breakdown voltage may become less than normal operating voltage level.

2.2. Ground-fault path

Ground fault paths are analyzed for the above mentioned modes.

Aging
Usually, conductor is the hottest and has the highest electric field in the cable. It is considered that heat and/or electric deterioration starts near the conductor.
Sometimes fault current path runs from the starting point (conductor) to the shielding layer in the shortest distance. Sometimes the path runs along the insulation paper gradually and the fault current path includes longitudinal direction.
In a cable fault due to the aging, therefore, both short and long fault paths can occur, as shown in fig.1.

Movement of cable core or external stress
In this case, it is considered that the fault path starts the damaged part, runs the shortest path through the insulation.

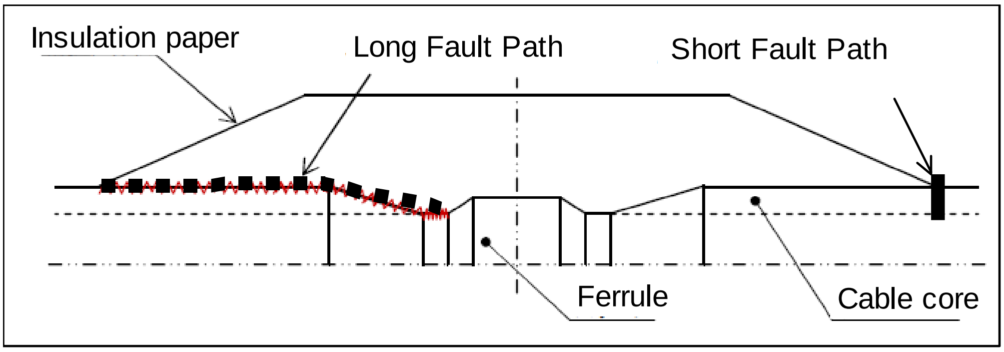

Figure 1: Example of fault paths in joint

Absorption of moisture

The moisture absorbed in oil-impregnated papers weaken the insulation. Decade ago, many ground-faults occurred in joints which had a problem in water barrier. The Experience shows that fault current runs the shortest path through the insulation on the end of joint insulation.

Negative oil pressure

Because it was not clear whether the fault path is short or long under negative oil pressure, full-scale tests were curried out, as shown in the following section.

3.GROUND-FAULT OF SCOF CABLE UNDER NEGATIVE OIL PRESSURE

Though SCOF cables should be used under positive oil pressure, negative oil pressure is possible when there is an incident to the oil feeding system, then, full-scale tests were carried out to know the effect of the negative oil pressure.

3.1.Test condition

Test sample

- Cable: 275kV SCOF with corrugated aluminum sheath 1x1400mm^2
- Joint: 275kV SCOF straight joint

Test Procedure

A tower about 14m high was set up, and the joint was laid on the top of the tower as shown in fig.2. Terminations were assembled in both ends of cable. The oil pressure of joint can be controlled from 0.1MPa(G) to minus 0.1MPa(G) by controlling the pressure of the oil tank on the ground. During the -0.1MPa(G) condition, there is no vacuum void in the joint and the insulation oil filled the joint.

Test voltage

159kV constant (normal voltage to ground)

Measurement item

- Surface level of oil in the cable oil duct and joint case
- Oil pressure of joint
- Partial discharge (PD)
- Dissolved Gas analysis (DGA)
- Dismantling and observation of the joint after the fault, to check the fault path

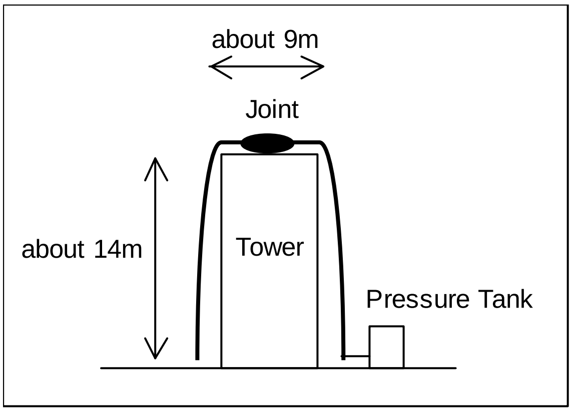

Figure2: Profile of full-scale test

3.2.Test result

Test result are shown in table1.

Result of dielectric breakdown test

While AC 159kV is being applied, the oil pressure of the joint was relieved gradually from positive pressure to negative pressure. Partial discharge (PD) was not detected under negative oil pressure before reaching to minus 0.1MPa(G). After reaching minus 0.1MPa, PD was measured. The results are all the same in the three tests. The breakdown occurred 1-7 hours after PD started. The faults occurred in the joints, not the cables in all the tests.
The joints normally withstand more than 420kV, which is required withstand voltage. In this test, it is shown that insulating strength of the joint under negative pressure, minus 0.1MPa(G), was less than 40% of that under the positive pressure.

Fault path

Observation results showed that the fault paths in three tests are all the same. Paths were long fault paths; from the ferrule surface or the conductor surface near the ferrule to surface of cable core, then to the cable/joint insulation screen.

DGA

After the breakdown, the oil of joints was sampled for DGA. Combustible gas including acetylene was found. Longer duration of PD made more acetylene gas.

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Table 1: Test Results

	Test 1	Test 2	Test 3
Applied Voltage	159kV		
Pressure of joint at PD start	-0.1MPa (G)		
PD duration before breakdown	approx. 6 hours	approx. 7 hours	approx. 1 hours
DGA after fault	C_2H_2: 467ppm TCG: 1,045ppm	C_2H_2: 465ppm TCG: 1,143ppm	C_2H_2: 333ppm TCG: 676ppm

4.DEVELOPMENT OF FIRE PREVENTION METHOD

4.1. SHORT-CIRCUIT TEST

It is very difficult to analyze the phenomenon of the cable ground-fault. Therefore short-circuit tests using full-scale cables and joints were carried out. Tests are carried out in CRIEPI (Central Research Institute of Electric Power Industry), which is laboratory accreditation granted by the Japan Accreditation Board for Conformity Assessment (JAB) in compliance with ISO/IEC17025.

The test condition is as follows.

- Installing real cables and joints
- Making the fault point by a metal nail
- The conductor and the sheath are short circuited, using short circuit current generator
- Fault current and its duration are decided based on the power system condition
- Tested in the similar environment as the actual installation using a mimic tunnel (fig.3 and fig.4)

Test result showed the following mechanism of fire ignition and spread

- Short-circuit arc decomposes oil and insulating paper
- The inner pressure of cable/joint increases.
- Arc itself and inner pressure rise destroy cable sheath or joint case.
- Arc heating ignite fire of leaked oil and paper
- Supply of oxygen spreads fire

Test results showed that longer fault path made larger arc power, and it caused bigger explosion.
Fire protection for long fault path is severer than that for short fault path.

Figure 3: External view of mimic tunnel

Figure 4: Example of short-circuit test

Figure 5: Ignition by ground-fault

4.2.Target of fire prevention method

Maintenance in TEPCO was checked whether each assumed ground-fault mode could be found and actual cable fault could be prevented.

Aging
It is extremely improbable that OF cables in service are rapidly aged in short time. Therefore aging can be found by regular DGA.

Movement of cable core or external stress
Movement of cable core can be found by regular cable inspection and DGA. Accidental external stress, including earthquake, may cause cable fault.

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Absorption of moisture
Slow absorption of moisture can be found by regular DGA. But if aluminum sheath is not good, including corrosion, moisture may be absorbed rapidly. It may cause fault.

Negative oil pressure
Appropriate maintenance of oil quantity and pressure can prevent the negative oil pressure.

It is considered that fault by aging and negative oil pressure can be prevented by appropriate maintenance. Therefore the target of fire prevention method in TEPCO is external stress and rapid absorption of moisture, in which short fault path is expected. Therefore, the target of fire prevention is only for short fault path.

Numbers of short-circuit tests were carried out. If fire is caught, measures to prevent fire were studied and then retested.

As a result, Fire prevention method including fiber-reinforced plastic (FRP) trough and aramid sheet is applied in TEPCO.

5.FIRE PREVENTION METHOD

Fire prevention methods in TEPCO developed based on the short-circuit tests are shown in this section.
Development concept is as follows.

- Fire does not burn the other circuits.
- Scattered materials do not harm the other circuits.

5.1.Cable

Cable in tunnel
In tunnel, cables are laid in FRP trough (see fig.6). It blocks oxygen supply and prevent catching fire. It is important that the trough should not be broken nor the trough cover should not be displaced by explosive pressure. It is necessary to design proper material, cross-sectional area, and thickness of trough, and to choose proper material, width, and interval of the bands binding trough cover. Specifications are decided by calculations and short-circuit tests.

If the specificarions of trough and its band are fixed, binding interval is controlled so that the trough cover should not be displaced in assumed pressure. Pressure generated by the fault depends on fault current and cross-sectional area of the trough. And necessary binding interval is decided accordingly.

Fault current becomes larger as the power system expands, and the generated pressure inside the trough becomes larger, too. It is not reasonable if the binding interval is too short. Trough itself may not withstand the fault shock. In this case, the spec of trough may be modified, or the trough may have a pressure discharge function.

Figure 6: Example of fire prevention method for cable in tunnel by FRP trough

Cable offset and cable in shaft
In cable offset and shaft, where it is difficult to apply FRP trough, plastic hose and aramid sheets are applied as shown in fig.7. Plastic hose works as anti-arc protection and keeping shape, aramid sheets work as anti-pressure protection.

Figure 7: Example of fire prevention method for cable in shaft

5.2.Joint

Aramid sheets including FRP trough are applied to joint as shown in fig.8. FRP trough works as anti-arc protection and keeping shape. Alamid sheets work anti-pressure protection.
As cable in tunnel, it works to stop supplying oxygen and catching fire.
As it is difficult to confine the pressure of the fault in the limited space around the joint, pressure discharge function is applied, which relieves the pressure to both ends of the joint (see fig.9).
Because cross-section area of aramid sheet becomes smaller at the transition from the joint part to the cable part, relatively high pressure occurs there. Therefore the aramid sheets at the transition part are designed to properly absorb pressure. Sheet sewing/bolting parts may

be a weak point and they are carefully developed. Specifications are decided by calculations and confirmed by short-circuit tests. There are ancillary facilities including cross-bonding cables, oil feeding pipes, and pipes for oil sampling around the joint, which makes holes in the aramid protection. It was confirmed that those holes do not affect the fire prevention performance.

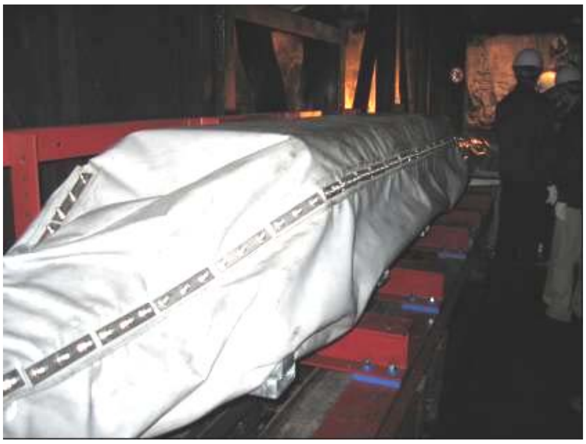

Figure 8: Example of fire prevention method for joint

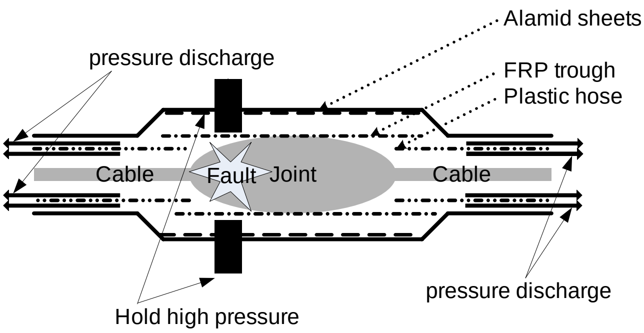

Figure 9: Pressure discharge function in joints

6.CONCLUSION

Fire may occur when a EHV SCOF cable faults in a tunnel
EHV SCOF cable has large ground-fault current, and the chance of catching fire at the time of fault is very large.

Fault path at negative oil pressure is “long fault path”
Effect of negative oil pressure was analyzed. It was found that SCOF cable can not withstand normal voltage under negative oil pressure, and that the fault path is “long fault path” .

Fault energy is large when the fault path is long
Short circuit tests show that long fault path makes large fault energy compared to short fault path. It is not practical to confine the energy, and preventive maintenance is important to prevent it.

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