Leak Current Monitoring System On The Ground Cables Medium Voltage Transformer 150/20 kV

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Abstract. On January, 2017 there had been fault trip at PMT 150/20 kV transformer in Jatirangon substation. For fault detection, that rele differential phase T and REF 20 kV have worked to detect this fault. The resulted impact of this fault is Power outage in feeder a 1350 A, 35 MW and 5 Mvar. The cause of this fault is the occurrence of breakdown on ground cables 20kV T-phase-core 1. This results in a short circuit to the ground so that the differential protection relay and REF 20kV work because the relay detects a fault in the ptotection zone. The result of this research is the design of an early detection monitoring tool. This tool is used to determine the amount of leakage current on the ground cable in order to minimize the occurrence of interference that causes the occurrence of electrical power outage. The result of the leakage current monitor on the ground phase cable T obtained a current of 0.6A with temperature 35 ^{o}C. With thermal failure calculation method for leakage current obtained result of 0,56180A with temperature 35 ^{o}C. Comparison of the calculation with the measurement of leakage current on the ground cable T phase is obtained at 6.36%.

1 Introduction

The distribution of electric power transformer power *step down* voltage of 150 kV System to a 20 kV medium voltage (MV) system in large capacity, is generally done using a medium voltage cable. Distribution of electrical energy step down power transformer from 150 kV voltage system to 20 kV medium voltage system in a large capacity, generally carried out using medium voltage cable network. This is because for the distribution of 20 kV medium voltage power System air conduct is sometimes difficult to implement because it reduces the aesthetics of space. For this reason, an important factor to be considered in using ground cable is the isolation characteristics. One of the obstacles to the use of ground cable is the failure of isolation in carrying out its function as a medium voltage isolation medium. Because in the manufacture of cables is sometimes not perfect so there are cavities in isolation. If the rate of heat at a point in the cable material exceeds the rate of heat dissipation, there will be an unstable state and at some point the material will cause a thermal failure.

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If this thermal failure lasts a long time, it will reduce the reliability of the cable so that it will cause isolation failure and damage to the cable. The failure of the isolation of the 20 kV medium voltage ground cable occurred in the 150 kV / 20 kV Transformer #4 at the Jatirangon Substation, which caused a disturbance and the electrical power outages. Before the occurrence of fault, no monitoring of the leakage current of the power cable was made so that it was not detected early that an increase in the leakage current of the medium voltage cable resulted in the Fault. For this reason, it is necessary to have a tool to detect early increase in the MV leakage current so that it can minimize the disturbance that causes the power to be disconnected to the consumer, the productivity stops and causes losses to the Industries due to damaged equipment.

2. Transformer protection

The transformer as the main equipment at the substation that functions to distribute electrical energy to the distribution electricity system must be protected properly. Because when the transformer is damaged will cause the flow of electricity to the distribution network is disconnected. The transformer is protected by using protection relay, the relay is in charge of identifying the fault that occurs in the transformer, fault around the transformer, and fault with the network supplied by a transformer. If a fault condition or abnormal condition is found, the protection relay will give the PMT command to trip so that the transformer is free from system voltage and fault current.

The protection relay is grouped into 2 types of protection, namely mechanical and electrical relay. Beside that, transformer relays are also grouped based on the type of protection that is divided into the main protection relay and backup protection relay. The same mechanical and electrical protection relay function is to protect the transformer from the short circuit current by giving a trip command to the PMT. All mechanical relays are the main protection relay. This relay works without delay time (instant) when there is an internal or external fault of the transformer which causes in an anomaly in the transformer's internal. The following is an explanation of the electrical relay of the transformer.

2.1 Rele *differensial*

Differential relay is relays that work when detecting phasor differences and or instantaneous difference in input current and output current. The principle of this relay work is the comparison of the primary, secondary and or tertiary winding currents (if the tertiary is burdened). The working principle of this relay is based on Kirchoff's Current Law I, namely the amount of incoming current equal to the amount of current coming out at the point of branching of an electrical circuit.

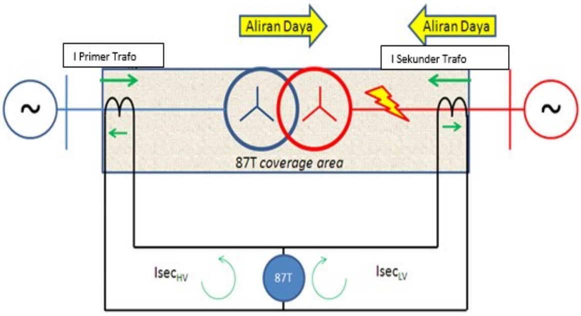

Fig. 1. Scheme of internal fault condition

In Figure 1 explains the workings of the RD when fault conditions. The current will not be detected by rele differensial as fault current when the transformer in case of normal operation because the primary current and the secondary current will cancel each other at point 87T. In this normal condition the differential relay does not detect the difference in the incoming and outgoing currents, so the differential relay does not work. But on the fault condition, *differensial* Relay feels any difference in inflows and outflow. So that RD will operate to give trip commend to PMT.

When the fault is outside the relay protection zone, the current from the primary side and the current from the secondary side will also cancel each other at point 87 T even though the magnitude of the fault current is large. In this condition the differential relay does not detect the difference in the primer current and the secondary current so that the differential relay does not work. Figure 1 decribes the Fault condition in Protection Zone. In this condition *differensial* rele detected any difference in primer current and secondary current, so rele *differensial* will operate.

The different current will be read on the workings of the relay differensial while the transformer is in a State of abnormal in the protection zones rele. Current from the primary side and the secondary side of each other add up at this point 87T. So in this condition RD detect any difference on primer and secondary (primer does not equal secondary). So RD worked for gave orders for the trip because the PMT occur in the protection zone. So in general the workings of RD is when the disruption is outside the protection zone then the sum of the currents is zero at the point of branching (*restraint point*). However, in the event of fault in the area of protection then the incoming current is no longer equal to the secondary current so that it will arise at the point of differensial current in *restraint point*. If the difference in the current *differensial* has already reached the point settings then this relay will *operate*. In the condition of the transformer and the normal protection system the RD must be stable or not work if conditions occur as follows: Inrush current, External Throught Fault Current, Overfluxing on the transformer and Change tap on Load.

2.2 Rele restricted earth fault

REF Relay is used to protect the transformer from phase fault to the ground near the neutral point of the transformer. This relay is installed on the transformer with the YNyn vector group design grounded. This protection zone of REF is an area that is not detected by differential relays, so that the sensitivity of this relay becomes the main point of the setting. The magnitude of the phase fault current to the ground depends on the value of the resistance that is installed on the ground of the neutral point.

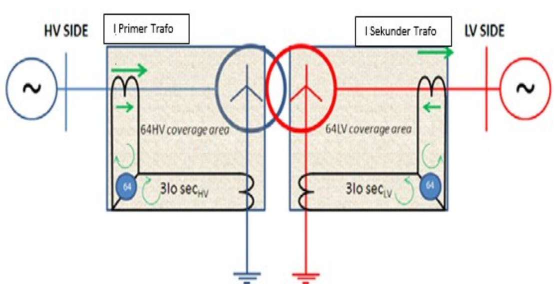

Fig. 2. Scheme of rele REF

Figure 2 describes how to work with the reading of current when the transformer operates normally. The working principle of relay REF is the same as differential relay, using Kirchhoff Current Law I that is the incoming current equal to the current coming out at the point of branching of an electrical circuit or at restrain points. In 1 power transformer with 2 windings there are 2 REF relays each protection the primary and secondary sides of the transformer. The detection of the current on the REF relay in the event of a ground fault on outside the protection zone, the REF relay will not detect because the current passing through the 64 is the same value. On the other hand, if the ground faults occurs inside the protection zone because the current passing through 64 is not the same value, the REF relay will operate.

3 Ground cable construction

Ground cable construction basically consists of 3 (three) important components, namely:

a. Conductor.

The conductor is intended as a good electrical conductor of low voltage, medium voltage or high voltage and called the core of the cable, including in the ground cable section. The electrical conductivity of a conductor material is expressed by conductivity, which is the opposite of resistivity, or the resistance type of conductor, where the resistance type is defined as:

$$\rho = \frac{R\ .A}{L} \tag{1}$$

Where A= cross-sectional area (m^2), L= Cable length(m), R= conduct resistivity (ohm-m), ρ= Conductivity

Table 1. Properties of aluminum

Properties of Materials	Unit	Alumunium (Ac)
Electrical Conductivity (ρ)	$(\text{ohm meter})^{-1}$	$3{,}8 \times 10^{7}$
Thermal Conductivity (k)	J / m.s °C	200
	Kkal / m.s °C	$500 .\ 10^{-4}$
Resistance Type	Ωm	$2{,}65 \times 10^{-8}$

On the research had used medium Voltage ground cable 20kV with a core made of aluminum is then seen table 1. Material aluminum has an electrical conductivity of $3.8\text{x } 10^{7}$ $(\text{ohm m})^{-1}$, thermal conductivity (k) of 200 J/m s ^{o}C and the resistance type of 2.65×10^{-8} Ωm.

b. Isolation

Cable isolation is often called the dielectric, whose function is to limit or to prevent direct contact between the conductors that are voltage with the surrounding objects.

c. Protective

Its Protective functions prevent the isolation from being affected from the outside such as the entry of water into the cable isolation, or humidity mechanical or pressure that could damage the cable isolation.

Figure 3. that is the kind of NA2XSY ground cable 1x150 cm/12/20 25 (24) kV declares a single nucleated, cables for nominal voltage 12/20 kV XLPE insulated, conductor, aluminum with a broad cross-section of $150mm^2$ copper layers, on the outside of

the core arrangement with a broad cross-section of 25 mm^2, PVC. These cables are used in this research are already installed on a trnasformator 150/20 GI Jatirangon 4 kV.

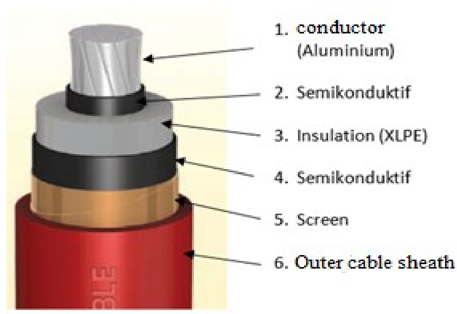

Fig. 3. Nucleated single ground cable

3.1 Process leaked current

3.1.1 Cavities on the cable

Inside the cable there are often cavities that contain gas or air. This gas or air cavity is formed during cable manufacturing or cable usage time.As it is known that a cable consists of several types of layers made of different materials and has different expansion coefficients. In case of heating and cooling, either at the time of manufacture or at the time of loading with the current depreciation expansion and then from each ingredient will differ. As a consequence will thus the cavity-cavity containing the gas or air between the layers that and cavity gas or air has a dielectric strength of materials isolation materials. The cavity on cavity-in isolation material can also arise at the time of manufacture. The air cavity is a hole with pressurized air and low power dielectric isolation, is the weak point of isolation because the permittivity is lower, it will be an increase in the electric field in the air in the cavity exceeds the power to penetrate the air. The cable damage processes is shown in Figure 4.

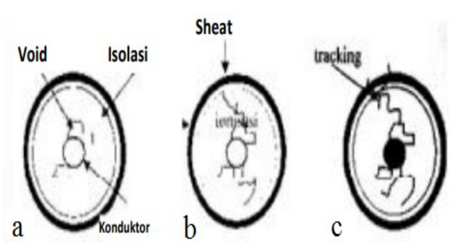

Fig. 4. Process of damage on Cable

3.1.2 Failure isolation

Cable insulation failure is a situation where isolation cannot anticipate an abnormal condition that exceeds the isolation capability. Isolation failure is caused by the type of electrode material, the configuration of the electric field, temperature, pressure, voltage, and the life time (age) of the used isolation material.

3.1.3 Failure of thermal

Thermal failure is a failure that occurs if the speed of heat at a point in the used material exceeds the rate of heat dissipation out. As a result there is an unstable failure so that at some point the material fails. The mechanism of thermal failure follows the laws of energy conversion, i.e., the heat generated is equal to the heat is channeled out through electrodes in the surrounding medium added with the heat is used to increase the material temperature. According to Whitehead, the minimum voltage of thermal failure (Vm) is:

$$V_m = \int_{Tm}^{To} \left| \frac{(8\,k)}{\sigma} \right| \; dt \tag{2}$$

Where : Vm : Voltage fails the minimum thermal [V], k : thermal conductivity [J / m.s ^oC]
To : Temperature on material surface (in this case equal to the temperature of the circumference) [^oC]
Tm : critical Temperature of faiedl materials, σ : electrical conductivity [ohm meter]$^{-1}$

3.1.4 Flow of leaked power cable

Leakage current is a current that flows through the isolation surface. Isolation serves to electrically separate two or more conductors that are close together, so that no leakage current occurs. Leakage currents also caused by leaky cavities on isolation material, which caused an error in the manufacture of isolation material. Isolation resistance affects the leakage current, the isolation resistance will be greater if the conductor gets longer. The equation of the prisoner's isolation as follows:

$$I_b = \frac{Vm}{R} \tag{3}$$

Where, I_b: Leak current [A], Vm : voltage fails the minimum thermal, R: thermal resistance [Ω]

3.1.5 Leakage isolation

Normally the current will flow through the cable conductor, while unwanted leakage current will flow radially from the conductor through the dielectric to the protective layer. In the cable cross section then it will become larger when it is started from the conductor.

3.2 Monitor concept of leakage current

To be able to monitor the leakage current on ground cables transformer-4 GI Jatirangon, then a device monitoring facilities of leaked cables was designed base on grounding. On operated

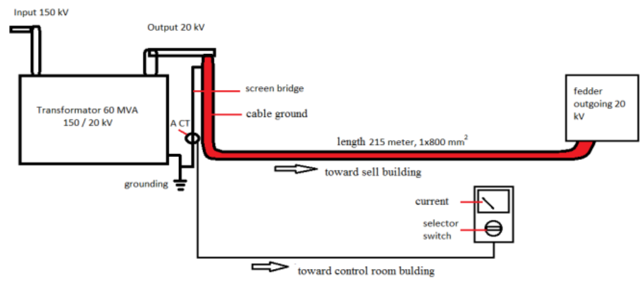

Fig. 5. Monitor of Leaked current on ground Cable

transformer, the only leaked currents of cable ground can be monitored. The leakage current flows from the part of the cable called the screen which is grounded on one side of the cable end. The screen functions as the location of the flow of short circuit current in phase fault to the ground to the nearest ground flow the capacitive current that arises in isolation because of the phase to ground voltage. For this reason, a leakage current monitoring facility can be made by using the screen that is grounded. To be able to monitor the current, a current transformer ring is used for current measurement. After that, the ct ring is connected to a measuring device so that it can monitor the current value. Because in T phase there are 3 cables with a core, then 9 CT rings are needed for each cable. For more details, see Figure 5 below.

3.3 Leaked current measuring

1 Monitoring the leakage current can be done in a calculation based on thermal failure by monitoring the temperature on the cable surface using flir. According to Whitehead the voltage of thermal failure can be calculated using formula 1 and the leakage current can be calculated using the formula 2.
2 Monitoring the leakage current when operating with a facility of leakage current facilities that have been made above by monitoring using ampere pliers, so that it is directly obtained from the leakage of ground cable.

Fig. 6. Monitoring leaked Current on the operation

4. Calculation of leaked current

Specifications techniques for ground cable for transformer 4 the length of the 215 meters with a cross-section area of 1x800 mm^2. Electrical conductivity, thermal conductivity and resistance type of aluminum can be seen in tabel 2.1. Then for conducting Resistance can be calculated by using the formula 1. By substituting the value of the parameter value, then the value obtained for the 20kV ground cable resistance is R = 0.00712 Ω. To get the value of the leakage current, the ground cable must first find the voltage of the thermal cable ground failure then the thermal failure voltage can be calculated by using formula 3.1 as follows:
Ground cable the T phase core 1:

$$V_m = \int_{Tm}^{To} \left| \frac{(8\,k)}{\sigma} \right| \, dt = \int_{130}^{35} \left| \frac{(8\,.\,200)}{3{,}8 \text{ x } 10^7} \right| \, dt = 0.004 \text{ V} \quad (4)$$

Then obtained for failed cable ground thermal voltage phase T core 1 for V_m = 0.004003 V. After a failed voltage rated thermal ground cable, then for the flow of leaked cables land can be calculated using the formula 3.2, with calculation as follows:

$$I_b = \frac{Vm}{R}, \; I_b = 0.56180 \text{ A} \quad (5)$$

After the calculated then obtained for the leaked cable ground T phase of core 1 for I_b = 0.56222A. For other cable core calculation result can be seen in table 4.1. For calculation results are smaller than the results of monitoring the equipment directly. For the calculation of the T core 1 phase ground cable with thermal failure method, the result of leakage current is 0.56180 A with a temperature of 35°C, while the results of monitoring the tool using the ampere pliers as a measuring device obtained the leakage current of 0.6 A with the same temperature 35° C. Based on the table above obtained for the results of manual calculations with monitoring tools have a deviation of results. Obtained for the difference between the calculation with the measurement of 6.36%.

Table 2. Comparison of calculation with the measurement of the leaked current.

Phase	Core Cable	Thermal (°C)	Calculation		Measurement (A)	Calculation : Measurement (%)
			V_m (V)	I_b (A)		
R	1	33	0.00140	0.57163	0.8	28,54
	2	20	0.00463	0.65028	1,1	40,88
	3	30	0.00421	0.59129	0,8	26,08
S	1	20	0.00463	0.65028	1,1	40,88
	2	25	0.00442	0.62079	0,9	31,02
	3	20	0.00463	0,65028	0,8	18,71
T	1	35	0.004	0.56180	0,6	6,36
	2	20	0.00463	0,65028	1,0	34,97
	3	20	0.00463	0.65028	1,2	45,81

The difference between the calculation with the measurement because in the manual calculation only calculates the value of leakage current contained in the ground cable, while the results of the measurement of the value of leakage current monitored on the ground cable and transformer on the secondary side so the results are greater.

5 Summary

To find out the leakage current of ground cable manually, thermal failure method is used by monitoring the cable surface heat results. After that it was analysed by using whtehead theory calculations. The results of leakage current of T phase core 1 ground cable is 0.56180 A with a temperature of 35°C. While using a equipment to monitor grounding-based leakage current for the ground cable results in 0.6 A with the same temperature 35°C. Difference in current 20 kV ground cable leakage of T phase core 1 transformer in Jatirangon substation between calculations with measurements of 6.36%.

With a leakage current monitor equipmen can detect early on the leakage current. If there is a significant increase in leakage currents, there can be a minimization of fault caused by a recurring ground cable breakdown so that electricity distribution to consumers and electrical equipment at the Jatirangon substation becomes more reliable.

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