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Protection of Three Phase Power Transformer

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Abstract: Transformers must be protected in order to limit the damages due to abnormal currents and over voltages. The role of protection is to ensure that these withstand limits can never be exceeded, therefore clearing the faults as soon as possible. Different transformers demand different schemes of transformer protection depending upon their importance, winding connections, earthing methods and mode of operation. The protection of transformer is important as it involves human risk as well as economic risk. There are different types of protection provided to a power transformer such as a Differential protection and Restricted Earth fault protection which together are known as Primary Protection Schemes; Backup Protection is also employed namely three phase overcurrent and earth fault. There are different types of protection equipment's available on a transformer like Buchholz relay, winding temperature indicator, oil temperature indicator, oil surge relay and pressure release valve etc. To avoid any danger to human life as well as to save transformer from any kind of damage, protection to a transformer should be provided. Index terms: Buchholz, Differential, Restricted Earth fault, Oil Surge Relay, Pressure Release Valve.

Keywords: Differential Protection, Restricted Earth Fault Protection, Three Phase Overcurrent and Earth Fault, Buchholz Relay, Winding Temperature Indicator, Oil Surge Relay, Pressure Release Valve

I. INTRODUCTION

The electrical power produced at generating stations needs to be transferred over high voltages transmission lines to the load center. Over the years, many protections are employed on a power transformer to protect it from any damage due to the fault. They are in operation all the time and are out of service just for regular maintenance or during power interruptions. Also, units contain very costly equipment ranging from copper, steel cooling oils, etc. There are severe faults, failures which occur in the transformer and damage the winding insulation, windings, etc. which needs to be protected. The life of a transformer is directly proportional to the life of its insulation. Major protections schemes used are Differential protection scheme, Restricted Earth Fault protection and the protection equipment's used are Buchholz Relay, Oil Surge Relay, Winding Temperature Indicator, etc.

II. PROTECTION SCHEME

2.1 Differential Protection

The differential protection is one of the main protection scheme which protects three phase transformer. This is because the efficiency of the power transformers is high and the magnetizing current is negligibly small. In differential protection,'' A differential relay responds to vector difference between two or more similar electrical quantities.'' According to the definition of the differential protection, the differential relay consists of two flowing quantities like current($I_1$and I2). These flowing quantities should be similar i.e. current/ current. This differential relay act to the vector difference between two flowing quantities i.e.(I1 -I2). Basically differential protection is a zonal protection which is determined by the position of circuit breaker. The vector difference is obtained by proper connection of current transformer and voltage transformer. According to the principle of differential protection of the transformer, under no internal fault condition, the incoming current in the primary winding is equal to the outgoing current in the secondary winding, so it shows the condition (I1=I2). The respective incoming and outgoing current in the primary and secondary winding is also equal in phase and magnitude. Both currents I1 and I2 are flowing through the pilot wires. In normal condition, the currents are flowing in the same direction due to the polarity connections of current transformer. Relay operating coil is located at the middle of the pilot wire.

During normal condition ratio are such that secondary currents of current transformer are equal. The vector differential current which is flowing through the relay coil is equal to zero. i.e. (I1 -I2=0). When fault occurs in the protected zone, incoming current is no more similar to the outgoing current. Because some current flows to the fault. The relay operating coil and relay is operating if the operating torque is more that the restraining torque. Currents are flowing in the secondary circuits; therefore, current transformer will not get damaged. Following are some difficulties present in the differential protection:-

It is impossible to connect relay coil and similar potential points. The current transformer and machine are also situated at the different points on the sites. This difficulty arises due to difference in the length of the pilot wire, and hence it is solved by adjusting series resistors with pilot wires.
During short circuit condition, primary currents are tremendously high. On the other hand, ratio errors of current transformer differs at short circuits. But this ratio differs due to inherent difference which is obtaining because of difference in magnetic circuits and saturation conditions, also due to unequal dc components in the short circuit currents.
Sometimes magnetic circuits of current transformer get saturated at the time of short circuit condition. Therefore, relay in the current transformer can also operate for external faults and might get unstable. To resolve this problem, the 'Percentage Differential Relay' or 'Biased Differential Relay' is used. There is differential relay present with additional restraining coil. This restraining coil is equal to the $(I_1 - I_2)/2$ which prevents the relay to operate during external faults. The rise in the current is increases as well as difference between both the currents which is obtaining due to difference in ratio of current transformer will not enough to cause the relay operation.
When transformer is connected to the load, sudden huge current starts flowing through the transformer called as inrush current and it is 6 to 10 times larger than normal current. So it causes to operate differential relay under no fault condition in the transformer. To resolved this problem harmonic restraint is added with the differential relay which filtered the harmonic components from the inrush current and then it delivered to the restraining coil. Also there is presence of harmonics in the magnetizing current. It is used to produce restraining torque while switching in the transformer.
While changing tap, it results change in the transformation ratio of the transformer. This is main reason of tap changing. This results in current in pilot wires during healthy condition. Also ratio of current transformer will not match with new tap setting. This is overcome by biased differential relay.
In the three phase circuit like three phase transformer, during normal condition current is not flowing through relay coil as well as secondary currents of current transformer are balanced. When fault occurs at that time differential current flows through the relay coil. The relay operates if differential current is more than the specific value. The main reason behind using of biased differential relay or percentage differential relay is to resolve the problem obtained due to huge rising difference of current transformer ratios for high values of short circuit currents. Basically it is used to prevent the malfunction by increasing restraining torque. The ratio of differential operating current to average restraining current is fixed percentage, so it is called as 'Percentage Differential Relay'. The relay is also called as 'Biased Differential Relay' due to biased coil (or restraining coil), it also provides additional flux. The magnitude of the current is directly proportional to the restraining current. The setting of differential relay has two methods:

1) Setting of operating coil circuit
2) Setting of restraining coil circuit

Following are factors should be considered at the time of setting:
1) Current transformer errors
2) Tap changing
3) Resistance of pilot wires
4) Stability for through faults

Now in the system under normal condition secondaries of current transformer are properly connected. But in the faulty condition, the secondary currents on the both sides of current transformer will oppose each other and the voltage is stabilized. When the internal fault occurs, at that time $(I_1 - I_2)/2$, current starts flowing through relay coil When the protection is related to air gap core, where core does not get saturated at that time current transformer are used. At normal condition, over voltages are not produced during zero secondary current.

2.2 Restricted Earth Fault Protection
Basically earth fault is a fault which is occurs between the earth and live conductor. During the fault condition, the short circuit current is circulating through circuit as well as fault current returns through the earth or any electrical equipment. This fault current can damage the system, also it can break the flow of the power supply. This earth fault can be detected with the help of restricted earth fault scheme. In the restricted earth fault protection scheme, earth fault relay is present. As soon as fault is detected, it gives the tripping command to the circuit breaker. So this way the fault current will get eliminated from the system. The earth fault relay will protect the delta winding or star winding which is

not connected to the earth of the power transformer from the fault current. On both the sides of protective zone current transformers are present; the earth fault relay is placed in parallel connection with the secondary terminal of current transformer. Therefore, output and the zero sequence current of the current transformer are similar to each other. During external fault condition, the zero sequence current is not available. But at the time of internal fault, the zero sequence is twice than fault current. It concludes that in the protective zone, an earth fault relay will not operate during external fault condition. It will operate only during the internal fault condition.

The earth fault relay should be highly sensitive, because it is capable enough to sense the fault currents. The relay should be highly accurate to sense 15% high fault current than the rated winding current. This setting can protect the restricted portion of the transformer winding. So this protection scheme called as “Restricted Earth Fault Protection”. To remove the magnetizing inrush current, the earth fault relay is connected in series with the stabilizing current. When the neutral of the power transformer is connected to the current transformer, it is called as “Neutral Current Transformer”. In the power transformer, under unbalanced condition of three phases, the common terminals of current transformer secondaries are connected to the closed path at the time of unbalance current flows through closed path. When unbalance current flows through neutral terminal of the power transformer, that time secondary current in the neutral current transformer is present due to unbalance neutral current. In restricted earth fault protection scheme the secondary unbalance current of phase current transformer and secondary current of neutral current transformer will oppose each other due to some specific connection of common terminals of phase current transformer with secondary of neutral current transformer. It concludes that, there is no resultant current flowing through closed path if currents are equal in the amplitude. The Restricted Earth Fault Relay is connected in this closed path, so the relay will not respond if there is an unbalancing in phase current of the power transformer.

2.3 Over current and Earth fault protection

Basically earth fault protection and over current protection is also known as Backup protection of the power transformer. Backup protection of the power transformer is to simply protect the devices from the excessive loads and external short circuits. The over current relay and earth fault relay are similar to the Inverse Definite Minimum Time Relay (IDMT) or Definite Time Type Relay (DMT). In the backup protection mostly used relays are Inverse Definite Minimum Time Relay (IDMT) which is connected to the infeed side of the transformer. Basically the overcurrent relay are not capable enough to separate out the internal fault, over load faults and external short circuits, for that purpose strictly backup protection is required. Therefore, overcurrent relay and earth fault relay are connected to the infeed side of the transformer, and therefore, it helps relay to operate in minimum time. The backup protection is mainly connected to the infeed side of the transformer, but it simultaneously breaks the primary connections and secondary connections of the circuit breaker. The over current relay and earth fault relay cannot break the primary side of the transformer like backup protection. Therefore, it cannot be connected to the output side of the transformer.

The operation is controlled by the setting of the time, current and the characteristics curve of the relay. It allows the similar relays to use the over load capacity of the transformer at about 125 to 150% of full load current capacity of the transformer but below the short circuit current. Backup protection circuit is constructed using three phase over current relay connected with each phase and the earth fault relay is connected to the common point of that three over current relays. The current setting range of the Inverse Definite Minimum Time Relay is in between 50% to 200% and for earth fault relay it is in between 20% to 80%. To obtain, the unrestricted earth fault protection, we have to connect ordinary earth fault relay across a neutral current transformer in the case of transformer winding with neutral earthed. The unrestricted over current and earth fault relays should have proper time to co- ordinate with protective relays of other circuit to avoid indiscriminate tripping.

III. PROTECTION EQUIPMENTS

3.1 Buchholz Relay

Buchholz relay is the protection equipment which is used in the transformer. Basically the buchholz relay protection is a mechanical fault detector for electrical faults in oil immersed transformers. Buchholz relay in the transformer is located in between piping of the oil conservator and main tank. For reliable operation shape of the conservator pipe is slightly inclined. Buchholz relay works independently. The relay is not affected by number of transformer windings, tap changer position, and instrument transformer. When tap changer is located on the top of the tank then, conservator has its own oil enclosure. At that time, tap changer has its dedicated Buchholz relay. The Buchholz relay is very accurate and highly sensitive detector. A Buchholz relay consist of two main parts: pivoted float and pivoted vane. Both the pivoted float and pivoted vane consist of mercury switch. The casing of the buchholz relay is occupied with oil as well as mercury switches are open simultaneously. When small faults occur in the transformer at that time in between fault location and top of the transformer some gases are produced. The gas bubbles are tapped in the casing of the buchholz relay protection, in the casing of the transformer oil is exchanged by gases. When the oil level in the

buchholz relay decreases simultaneously the float will float and mercury switch tilts, resulting in closure of an alarm circuit.
The large faults are occurs between the windings or phases of the earth within the transformer. When the large faults occurs at that time it causes to produce a huge volume of the gas and oil vapour which are difficult to move out from the transformer, so it produces the pressure and removes oil. This produces the fast flow towards the conservator from the transformer which is further responded by the vane. In the pipe to the conservator, the vane is responded to the high oil and gas flow. Then the circuit will trip which is closed by the mercury switch. The tripping time is totally depends upon the fault location and magnitude of the fault current. According to the certain tests, the tripping time of the circuit must be in the range of 0.050 – 0.10 seconds. The tripping time should not be greater than the 0.3 seconds. The gas accumulator relay protects the different parts of the insulation systems and transformer conductors from the overheating. It gives the long term accumulation of gasses. It also indicates the fault sources at early stage of the circuit which prevents the system from damage. When the transformer comes into the service, at that time air which is present in the winding may give rise to sudden alarm indications. At this time, tank of transformer is filled with oil. The air in the winding of power transformer is removed by vacuum treatment. The Buchholz relay also indicates the reduction in the oil level due to leakage from the transformer tank.

Following are some limitations of the Buchholz relay:
1) It only detects fault under the oil level.
2) The mercury switch is not too sensitive, because it helps to operate relay during false conditions like earthquakes, presence of birds on the pipe, mechanical shocks to the pipe.
3) The tripping time of the relay is equal to 0.1 second, which is acceptable. It should not be more than 0.1 seconds because average time is 0.2 seconds under fault conditions. It is accepted till relay that indicates the failure of equipment.
4) Buchholz relay cannot be fitted to the transformer below rating of 500KVA.

3.2 Winding Temperature Indicator
The winding of the transformer is a component which has highest temperature. When the load is simultaneously increasing, the temperature of the winding is also increases. The temperature of winding and top oil is measured to control the temperature parameters of the transformer. This temperature is measured using Winding Temperature Indicator and the temperature of Transformer oil is measured using Oil Temperature Indicator. Winding Temperature Indicator indicates the winding temperature of HV and LV winding of the transformer and triggers the cooler unit, it also gives the alarm of temperature rise. An indirect system is used to measure winding temperature, since it is dangerous to place a sensor close to the winding near to high voltage. The indirect measurement is done by means of the Thermal Image. The measuring system is filled with the liquid which changes its volume with rising of temperature. Inside the instrument, it is fitted with a heating resistance which is feed by a current proportional to the current following through the transformer winding. To do this we connect the terminal of the heating resistance with the bushing current transformer so that the reflection of change in load is reflected in winding temperature indicator. The heating resistance is feed by a current transformer associated to the loaded winding of the transformer. The increase in the temperature of the resistance is proportional to that of the winding. The sensor bulb of the instrument is located in the hottest oil of the transformer, therefore the winding temperature indicates the temperature of the hottest oil plus the winding temperature rise above hot oil level. Winding temperature of the transformer may rise due to increased loading of the transformer or due to some internal fault. Normally the Winding temperature indicator gives alarm at 85 degree Celsius and trip signal at 95 degree Celsius (General practice in India).

3.3 Oil Surge Relay

OSR protection is basically used to protected the internal fault in the On Load Tap Changer Circuits. It monitors the oil level in the OLTC Conservator Tank and then the force oil enters into or leaves from OLTC. OSR provided with the single element oil surge relay has been specially designed to operate with OLTC. OSR does not operate during change of Transformer Taps. It will operate when the surge is developed in the OLTC. Under normal condition, the OLTC OSR relay reads normal pressure, since the relay becomes active. A heavy fault inside of the OLTC incidentally generates pressure wave or Oil surge or Oil move in the direction of OLTC tank. If these flow rate exceeds the operating threshold of the damper, then the flap move the flow direction. Due to this movement, the reed switch will be actuated and it gives trip signal to the circuit breaker and hence, the fault will be removed. The main purpose of the OSR is to limit the damage to the OLTC during fault condition.

3.4 Pressure Release Valve
In case of a serious fault inside the Transformer, Gas is rapidly produced. This gaseous pressure must be relieved immediately otherwise it will damage the Tank and cause damage to neighboring equipment. This relay is mounted on

the top cover or on the side walls of the Transformer. This valve has a corresponding port which will be sealed by a stainless steel diaphragm. The movement of the diaphragm lifts the spring and causes a micro switch to close its contacts to give a trip signal to the HV and LV circuit breakers and isolate the transformer. A visual indication can also be seen on the top of the relay. For smaller capacity transformer, an Explosion vent is used to relieve the excess pressure but it cannot isolate the Transformer from the fault.

CONCLUSION

This paper explains us the various protections schemes applied as well as the various protection equipment's used for protection of transformer. These are applied to ensure the functioning of them in a proper manner and to maintain reliability of the system.

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