Kurdistan Engineers Union
Sulaimaniyah branch

A report about:

THE PROTECTION OF A TRANSFORMER'S

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The Protection of Transformers
Introduction:

Transformers are one of the most critical and expensive components of any distribution system. It is an enclosed static device usually drenched in oil, and hence faults occurring to it are limited. But the effect of a rare fault can be very dangerous for the transformer, and the long lead time for repair and replacement of transformers makes things even worse. Hence **power transformers protection** becomes very crucial. Faults occurring on a transformer are mainly divided into two types, which are, **external faults and internal faults**, to avoid any danger to the transformer, an external fault is cleared by a complex relay system within the shortest possible time. The internal faults are mainly based on sensors and measurement systems. We will talk about those processes further in the article. Before we get there, it is important to understand that there are many types of transformers and in this article, we will discussing mainly about power transformer that is used in distribution systems. You can also learn about the working of power transformer to understand the basics of it.

Basic protection features like overexcitation protection and temperature-based protection can recognize conditions that eventually lead to a failure condition, but complete transformer protection provided by relays and current transformers are appropriate for transformers in critical applications.

So in this article, we will talk about the most **common principles used to protect transformers** from catastrophic failures.

Transformer Protection for Different Types of Transformers

The protection system used for a power transformer depends on the transformer's categories. A table below shows that,

Category	Transformer Rating - KVA	
	١ Phase	٣ Phase
I	٥ - ٥٠٠	١٥ - ٥٠٠
II	٥٠١ - ١٦٦٧	٥٠١ - ٥٠٠٠
III	١٦٦٨ - ١٠،٠٠٠	٥٠٠١ - ٣٠،٠٠٠
IV	> ١٠،٠٠٠	>٣٠،٠٠٠

- Transformers within the range of ٥٠٠ KVA fall under (Category I & II), so those are protected using fuses, but to protect transformers up to ١٠٠٠ kVA (distribution transformers for ١١kV and ٣٣kV) Medium Voltage circuit breakers are usually used.
- For transformers ١٠ MVA and above, which falls under (Category III & IV), differential relays had to be used to protect them.

Additionally, mechanical relays such as **Buchholtz relays,** and **sudden pressure relays** are widely applied for transformer protection. In addition to these relays, thermal overload protection is often implemented to extend a transformer's lifetime rather than for detecting faults.

Common Types of Transformer Protection

١. Overheating protection
٢. Overcurrent protection
٣. Differential Protection of Transformer
٤. Earth Fault Protection (Restricted)
٥. Buchholz (Gas Detection) Relay
٦. Over-fluxing protection

Overheating Protection in Transformers

Transformers overheat due to the overloads and short circuit conditions. The allowable overload and the corresponding duration are dependent on the type of transformer and class of insulation used for the transformer.

Higher loads can be maintained for a very short amount of time if it is for a very long, it can damage the insulation due to **temperature rise above an assumed maximum temperature.** The temperature in the oil-cooled transformer is considered maximum when its ٩٥*C, beyond which the life expectancy of the transformer decreases and it has detrimental effects in the insulation of the wire. That is why overheating protection becomes essential.

Large transformers have **oil or winding** temperature detection devices, which measure **oil or winding** temperature, typically there are two ways of measurement, one is referred to **hot-spot measurement** and second is referred to as **top-oil measurement,** the below image shows a typical thermometer with a temperature control box from reinhausen used to measure the temperature of a liquid insulated conservative type of transformer.

The box has a **dial gauge** which indicates the **temperature of the transformer** (which is the black needle) and the red needle indicates the **alarm set point.** If the black needle surpasses the red needle, the device will activate an alarm.

If we look down, we can see four arrows through which we can configure the device to act as an **alarm or trip** or they can be used to **start or stop pumps or cooling fans**.

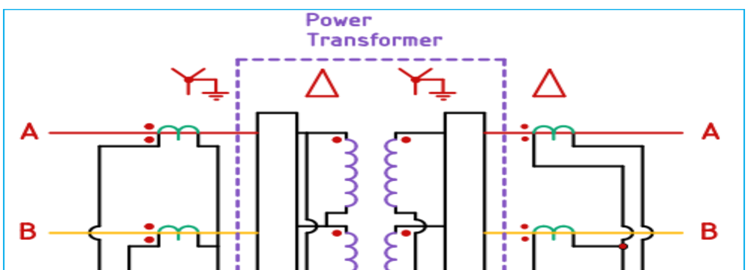
As you can see in the picture, the **thermometer** is mounted on the top of the transformer tank above the core and the winding, it's so done because the highest temperature is going to be at the center of the tank because of the core and the windings. This temperature is known as the **top oil temperature.** This temperature gives us an estimate of the **Hot-spot Temperature** of the transformer core. Present-day **fiber optic cables** are used within the low voltage winding to accurately measure the temperature of the transformer. That is how overheating protection is implemented.

Overcurrent Protection in Transformer

The overcurrent protection system is one of the earliest developed protection systems out there, the graded overcurrent system was developed to guard against overcurrent conditions. power distributors utilize this method to detect faults with the help of the IDMT relays. that is, the relays having:

١. Inverse characteristic, and
٢. Minimum time of operation.

The capabilities of the IDMT relay is restricted. These sorts of relays have to be set ١٥٠٪ to ٢٠٠٪ of the max rated current, otherwise, the relays will operate for emergency overload conditions. Therefore, these relays provide minor protection for faults inside the transformer tank.



Differential Protection of Transformer

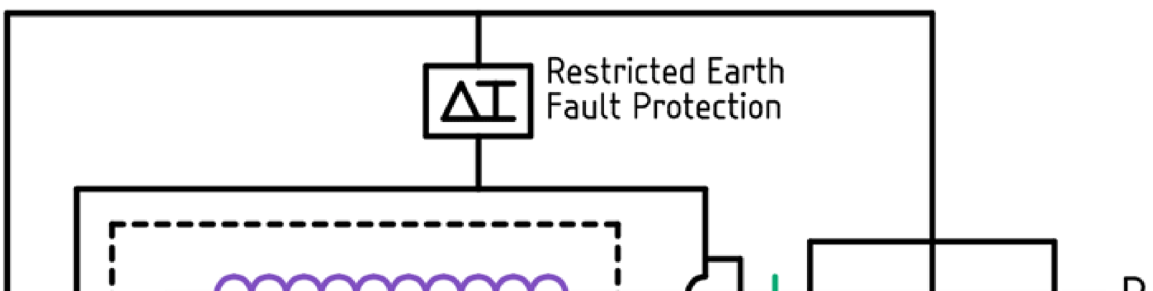
The Percentage Biased Current Differential Protection is used to **protect power transformers** and it is one of the most common **transformer protection schemes** that provide the best overall protection. These types of protection are used for transformers of rating exceeding ۲ MVA.

The transformer is star connected on one side and delta connected the other side. The CTs on the star side are delta-connected and those on the delta-connected side are star-connected. The neutral of both the transformers are grounded.

The transformer has two coils, one is the **operating coil** and the other is the **restraining coil**. As the name implies, the restraining-coil is used to produce the restraining force, and the operating-coil is used to produce the operating force. The restraining-coil is connected with the secondary winding of the current transformers, and the operating coil is connected in between the equipotential point of the CT.

Transformer Differential Protection Working:

Normally, the operating coil carries no current as the current is matched on both sides of the power transformers, when an internal fault occurs in the windings, the balance is altered and the operating coils of the **differential relay** start producing differential current among the two sides of the transformer. Thus, the relay trips the circuit breakers and protects the main transformer.



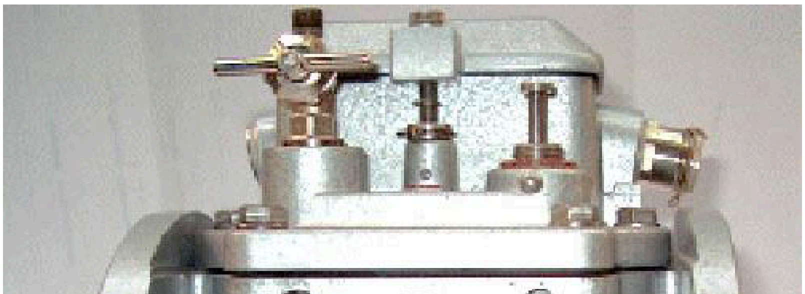
Restricted Earth Fault Protection

A very high fault current can flow when a fault occurs at the transformer bushing. In that case, the fault needs to be cleared as soon as possible. The reach of a particular protection device should be only limited to the zone of the transformer, which means if any ground fault occurs in a different location, the relay allocated for that zone should get triggered, and other relays should stay the same. So, that is why the relay is named **Restricted** earth fault protection relay.

In the above picture, the **Protection Equipment** is on the protected side of the transformer. Let's assume this is the primary side, and let's also assume there is a ground fault on the secondary side of the transformer. Now, if there is a fault on the ground side, because of the ground fault, a **Zero Sequence Component** will be there, and that will circulate only on the secondary side. And it will not be reflected in the primary side of the transformer.

This relay has three phases, if a fault occurs, they will have three components, the **positive sequence components, the negative sequence components, and the zero sequence components**. Because the positive sequins components are displaced by ١٢٠*, so at any instant, the sum of all the currents will flow through the protection relay. So, the sum of their currents will be equal to zero, as they are displaced by ١٢٠*. Similar is the case for the negative sequence components.

Now let us assume a fault condition occurs. That fault will be detected by the CTs as it has a zero-sequence component and the current starts flowing through the protection relay, when that happens, the relay will trip and protect the transformer.



Buchholz (Gas Detection) Relay

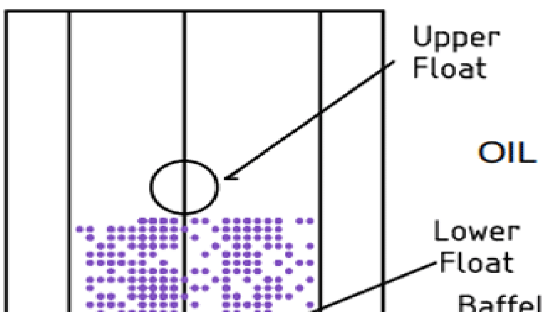
The above picture shows a Buchholz relay. The **Buchholtz relay** is fitted in between the main transformer unit and the conservator tank when a fault occurs within the transformer, it detects the resolved gas with the help of a float switch.

If you look closely, you can see an arrow, gas flows out from the main tank to the conservator tank, normally there should not be any gas in the transformer itself. Most of the gas is referred to as dissolved gas and nine different types of gasses can be produced depending on the fault condition. There are two valves at the top of this relay, these valves are used to reduce the gas build-up, and it's also used to take out a gas sample.

When a fault condition occurs, we have sparks between the windings, or in between windings and the core. These small electrical discharges in the windings will heat the insulating oil, and the oil will break down, thus it produces gases, the severity of the breakdown, detects which glasses are created.

A large energy discharge will have a production of acetylene, and as you may know, acetylene takes a lot of energy to be produced. And you should always remember that any type of fault will produce gases, by analyzing the amount of gas, we can find the severity of the fault.

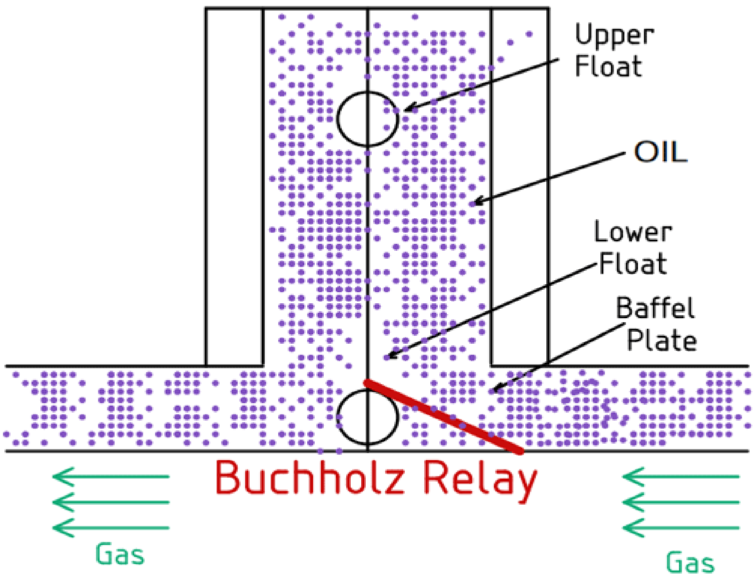
How Buchholz (Gas Detection) Relay Works?



As you can see from the image, we have two floats: an upper float and a lower float, also we have a baffle plate that is pushing down the lower float.

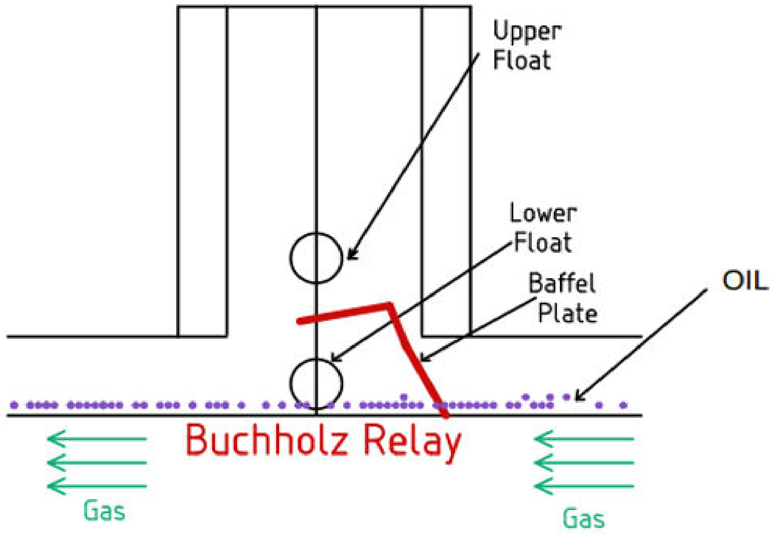
When a large electrical fault occurs, it produces a lot of gas than the gas flows through the pipe, which shifts the baffle plate and that forces the lower floated down, now we have a combination, the upper float is up and the lower float is down and the baffle plate has tilted. This combination indicates that a massive fault has occurred. which shuts down the transformer and it also generates an alarm. The image below shows exactly that,

But this is not the only scenario where this relay can be useful, imagine a situation where inside the transformer there is a **minor arcking** that is happening, these arks are producing a small amount of gas, this gas produces a pressure inside the relay and the upper float gets down displacing the oil inside it, now the relay generates an alarm in this situation, the upper float is down, the lower float is unchanged and the baffle plate is unchanged if this configuration is detected, we can be sure that we have a slow accumulation of gas. The image below shows exactly that,



Now we know we have a fault, and we will bleed out some of the gas using the valve above the relay and analyze the gas to find out the exact reason for this gas build-up.

This relay can also detect conditions where the insulating oil level falls due to leaks in the transformer chassis, in that condition, the upper float drops, the lower float drops, and the baffle plate stays in the same position. In this condition, we get a different alarm. The below image shows the working.



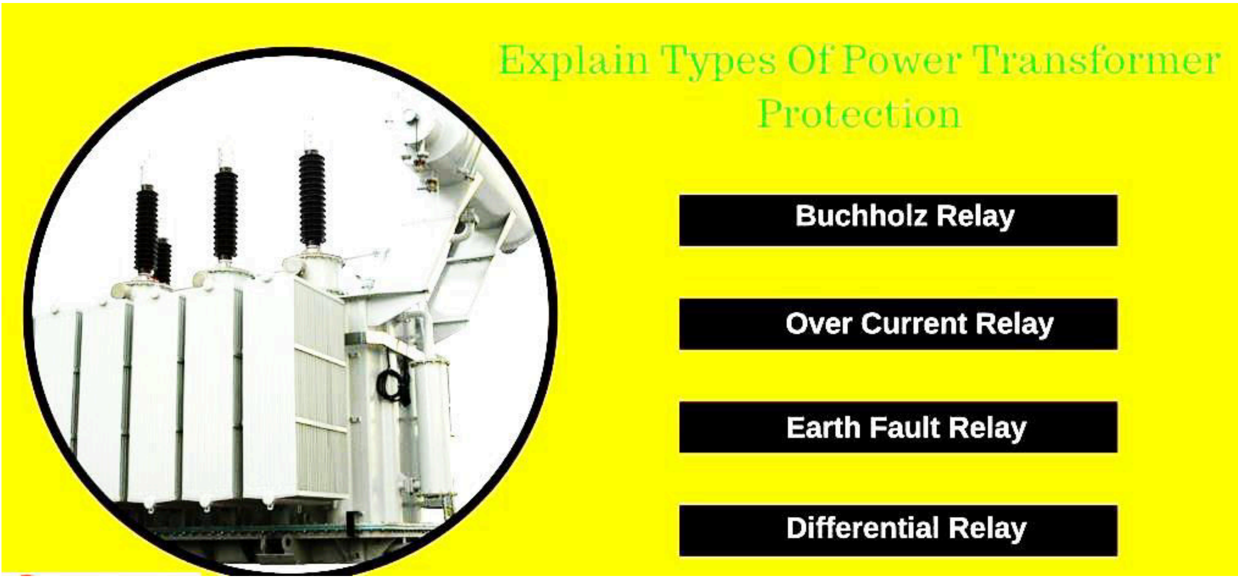
With these three methods, the Buchholz relay detects faults.

Over-fluxing Protection

A transformer is designed to operate at a fixed flux level exceed that flux level and the core gets saturated, the saturation of the core causes heating in the core that quickly follows through the other parts of the transformer that leads to overheating of components, thus over flux protection becomes necessary, as it protects the transformer core. Over-flux situations can occur because of overvoltage or a reduction in system frequency.

To protect the transformer from over-fluxing, the **over-fluxing relay** is used. The over-fluxing relay measures the ratio of Voltage / Frequency to calculate the flux density in the core. A rapid increase in the voltage due to transients in the power system can cause over fluxing but transients die down fast, therefore, the instantaneous tripping of the transformer is undesirable.

The flux density is directly proportional to the ratio of **voltage to frequency(V/f)** and the instrument should detect the ration if the value of this ratio becomes greater than unity, this is done by a microcontroller-based relay which measures the voltage and the frequency in real-time, then it calculates the rate and compares it with the pre-calculated values. The relay is programmed for an inverse definite minimum time (**IDMT characteristics**). But the setting can be done manually if that is a requirement. In this way, the purpose will be served without compromising the over-flux protections. Now, we see how important it is to prevent the tripping of the transformer from over-fluxing.



Transformer devices are electrical energy transmitting devices that transfer power electricity from one circuit to another via the magnetic field without making any changes in frequency. Power transformer exporters in World supply majorly two kinds of transformers to rest of the industries, i.e. Power transformers and distribution transformers.

How industries are making use of transformers?

In this era of modern transmission system, industries understand the importance of transmitting the power at high level. The process of electrical power production is not economical at such a high voltage. This is where transformers come in to enhance the level of voltage by generating voltage to higher level where the loss is very low.

Transformer is also used as booster in distribution system for a better regulation of voltage… below

What are the general faults occur in a transformer?

There are mainly four types of faults occur into transformer-

- Open circuit
- Winding short circuit fault
- Over heating
- Faults due to lightening

Is there any way to protect a transformer?

Yes, manufacturers suggest five ways to protect a transformer. These are as follows-

- Buchholz relay
- Over Current Relay
- Earth fault relay
- Differential Relay
- Digital relay

What do you understand about earth fault protection?

An earth fault includes a half-done breakdown of winding insulation to earth. It is advantageous to use an earth fault relay under such circumstance. Core balance protection is one the methods used for protecting Power transformers in World.

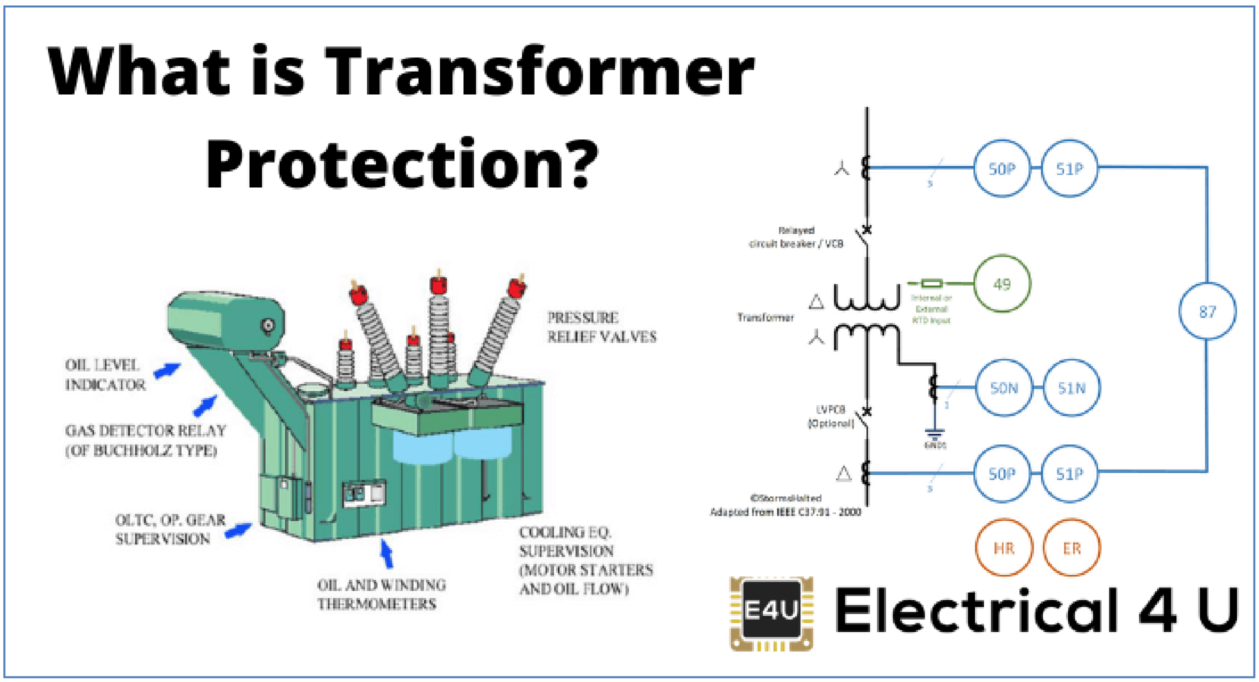
How one can protect the transformer from lightening?

It is always better to provide protection of transformer against surges and transient. Most of the time users of transformers implement certain devices for protecting transformers against lightening surges. A few devices are listed below-

- ✓ Overhead ground wires
- ✓ Earthing screen
- ✓ Lightning arrestor

Replacement of transformers is costly affair and time consuming. This is why user depends on high speed, highly sensitive and reliable protective relays to determine the faults. For this, differential protection has been used as main protection for most of the transformer devices.

Now you may ask what differential protection is. It is based on any fact in the electrical equipment that would let the current entering it, to be distinct from that leaving it. below ۱



Different transformers demand different schemes of transformer protection depending upon their importance, winding connections, earthing methods and mode of operation etc.

It is common practice to provide Buchholz relay protection to all ۰,۵ MVA and above transformers. While for all small size distribution transformers, only high voltage fuses are used as main protective device. For all larger rated and important distribution transformers, over current protection along with restricted earth fault protection is applied.

Differential protection should be provided in the transformers rated above ٥ MVA.

Depending upon the normal service condition, nature of transformer faults, degree of sustained over load, scheme of tap changing, and many other factors, the suitable transformer protection schemes are chosen.

Although an electrical power transformer is a static device, but internal stresses arising from abnormal system conditions, must be taken into consideration.

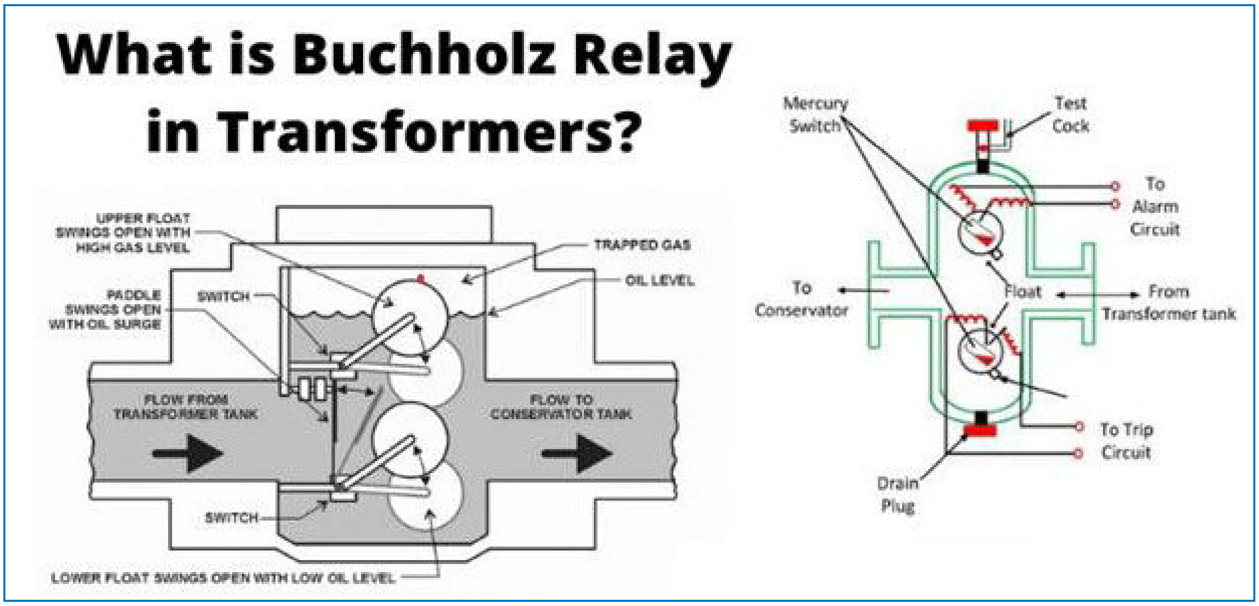
A transformer generally suffers from following types of transformer fault-

Over current due to overloads and external short circuits,

- ✓ Terminal faults
- ✓ Winding faults
- ✓ Incipient faults

All the above mentioned transformer faults cause mechanical and thermal stresses inside the transformer winding and its connecting terminals. Thermal stresses lead to overheating which ultimately affect the insulation system of transformer. Deterioration of insulation leads to winding faults. Sometime failure of transformer cooling system, leads to overheating of transformer. So the transformer protection schemes are very much required. [below ٢]

Buchholz Relay in Transformers

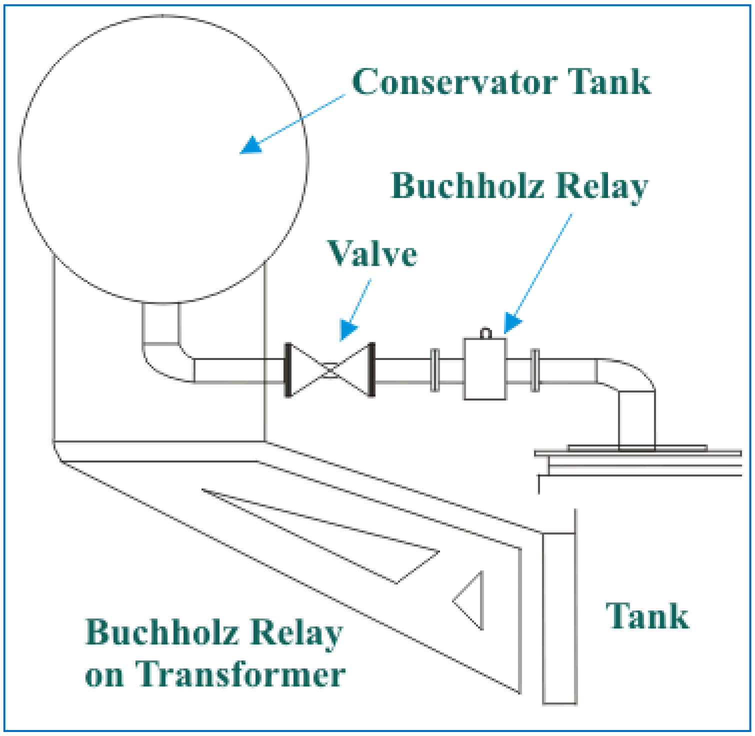


What is Buchholz Relay?

Buchholz relay in a transformer is an oil container housing the connecting pipe from the main tank to the conservator tank. It has mainly two elements. The upper element consists of a float. The float is attached to a hinge in such a way that it can move up and down depending upon the oil level in the Buchholz relay Container.

One mercury switch is fixed on the float. The alignment of the mercury switch hence depends upon the position of the float. The lower element consists of a baffle plate and a mercury switch. This plate is fitted on a hinge just in front of the inlet (main tank side) of Buchholz relay in a transformer in such a way that when oil enters in the relay from that inlet in high pressure the alignment of the baffle plate along with the mercury switch attached to it, will change.

In addition to these main elements, a Buchholz relay has gas release pockets on top. The electrical leads from both mercury switches are taken out through a molded terminal block. below ٢



Buchholz Relay Working Principle

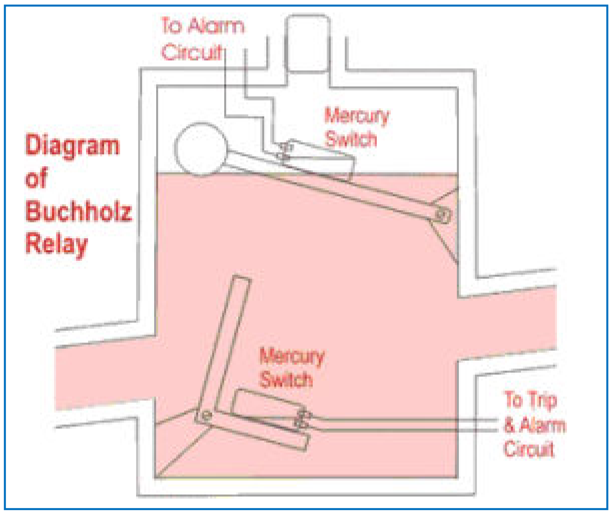
The Buchholz relay working principle of is very simple. Buchholz relay function is based on very simple mechanical phenomenon. It is mechanically actuated. Whenever there will be a minor internal fault in the transformer such as an insulation fault between turns, break down of core of the transformer, core heating, the insulating transformer oil will be decomposed in different hydrocarbon gases, CO_2 and CO. The gases produced due to the decomposition of transformer insulating oil will accumulate in the upper part the Buchholz container which causes fall of oil level in it.

Fall of oil level means lowering the position of the float and thereby tilting the mercury switch. The contacts of this mercury switch are closed and an alarm circuit energized. Sometimes due to oil leakage on the main tank air bubbles may be accumulated in the upper part of the Buchholz container which may also cause a fall of oil level in it and the alarm circuit will be energized. By collecting the accumulated gases from the gas release pockets on the top of the relay and by analyzing them one can predict the type of fault in the transformer.

More severe types of faults, such as short circuit between phases or to earth and faults in the tap changing equipment, are accompanied by a surge of oil which strikes the baffle plate and causes the mercury switch of the lower element to close. This switch energized the trip circuit of the circuit breakers associated with the transformer and immediately isolate the faulty transformer from the rest of the electrical power system by inter tripping the circuit breakers associated with both LV and HV sides of the transformer. This is how Buchholz relay functions. below٢

Buchholz Relay Operation Certain Precaution

The Buchholz relay operation may be actuated without any fault in the transformer. For instance, when oil is added to a transformer, air may get in together with oil, accumulated under the relay cover and thus cause a false Buchholz relay operation.



That is why the mechanical lock is provided in that relay so that one can lock the movement of mercury switches when oil is topping up in the transformer. This mechanical locking also helps to prevent unnecessary movement of breakable glass bulb of mercury switches during transportation of the Buchholz relays.

The lower float may also falsely operate if the oil velocity in the connection pipe through, not due to an internal fault, is sufficient to trip over the float. This can occur in the event of the external short circuit when overcurrent's flowing through the winding cause overheated the copper and the oil and cause the oil to expand. below ٢

TRANSFORMER IN GRID

Power transformer protection – an outline

What are the main protection types to protect major substation element?

ABSTRACT

Power transformers are used in High Voltage (HV) / Extra High Voltage (EHV) / Ultra High Voltage (UHV) systems as they transfer a huge amount of power to the customers but the volume of vulnerability and damage is also huge and destructive. Therefore, in order to avoid such destruction and loss, protective devices are used with different pro- tection schemes to provide safe and secure power to the customers. These devices not only protect the equipment but also preserve human life and secure the system from impairment.

Keywords

protection, relays, schemes, faults

١. Introduction

The transformers in HV networks are always protected by one main protection device and at least one back-up pro- tection device. Main Intelligent Electronic Device (IED) uses all the protection functions, and the back-up IED has at least an (overcurrent) OC low stage with Inverse Definite Mi- nimum Time (IDMT) curves, an OC high stage and an Earth Fault (EF) protection. In EHV we use two identical main pro- tection devices in a redundant protection system.

In the field of power systems, the role of a power transformer is well known. It is so called backbone of the power transmission systems. High reliability of the transformer is therefore essential to avoid disturbances in transmission of power. When a fault occurs in a transformer, the damage is usually severe. The trans- former has to be transported to a workshop and repaired, which

When a fault occurs in a transformer, the damage is proportional to the fault time. The transformer should therefore be disconnected from the network as soon as possible

٢. Failure statistics

Table ١ lists failures for six categories of faults (IEEE C٣٧,٩٠, *Guide for Protective Relay Applications to Power Transfor-mers,* Ref. ١). Winding and tap changers account for ٧٠٪ of fai- lures. Loose connections are included as the initiating event as well as insulation failures. The miscellaneous category includes CT failure, external faults, overloads, and damage in shipment. An undisclosed number of failures starts as incipient insulation breakdown problems.These failures can be detected by sophis- ticated online monitoring devices (e.g. gas-in-oilanalyser) be- fore a serious incident occurs [١].

٣. Transformer protection

When a fault occurs in a transformer, the damage is propor- tional to the dissipated fault energy which relates to the fault time. The transformer should therefore be disconnected from the network as soon as possible. Fast reliable protective relays are therefore used for detection of faults. Monitors can also detect faults and sense abnormal conditions which may de- velop into a fault. The size of the transformer and the voltage level has an influence on the extent and choice of protective equipment. Monitors prevent faults and protective relays li- mit the damage in case of a fault. The cost for the protective equipment is marginal compared to the total cost and the cost

takes considerable time. To operate a power transmission system with a transformer out of service is always difficult. The impact of a transformer fault is often more serious than a transmission line outage. To prevent faults and to minimise the damage in case of a fault, transformers are equipped with both protective relays and monitors. The choice of protective equipment varies depending on transformer size, voltage level, etc.

Table ١: Failure rates

	1955-		1975-		1983-	
	Number	Percent of total	Number	Percent of total	Number	Percent of total
Winding failures	134	51	615	55	144	37
Tap changer failures	49	19	231	21	85	22
Bushing failures	41	15	114	10	42	11
Terminal board failures	19	7	71	6	13	3
Core failures	7	3	24	2	4	1
Miscellaneous failures	12	5	72	6	101	26
Total	262	100	1127	100	389	100

involved in case of a transformer fault. There are often different opinions about the extent of transformer protection. However, it is more or less normal that transformers with an

The cost for the protective equip-ment is marginal compared to the cost involved in case of a transformer fault and the total cost

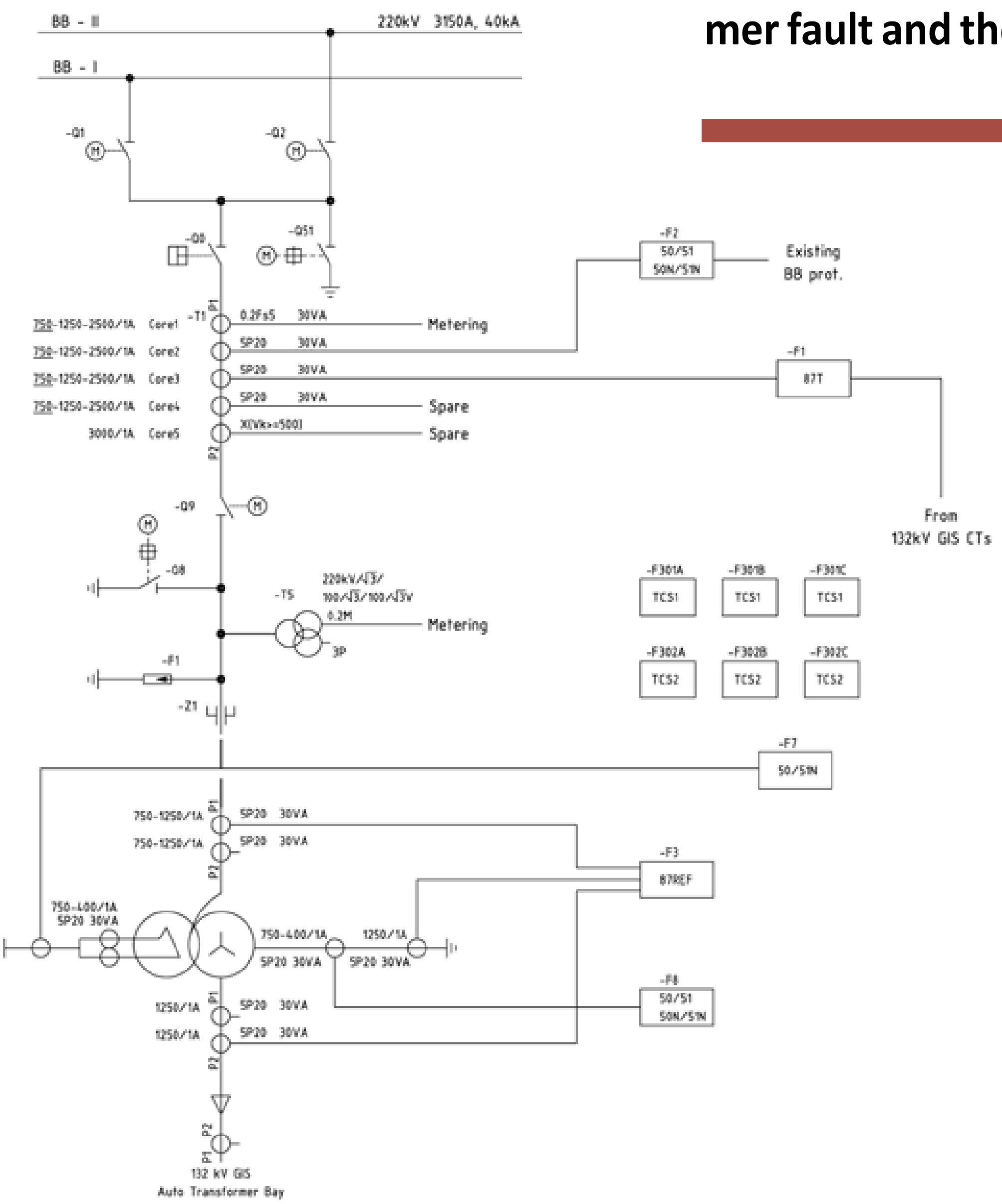


Figure ١: Typical single line diagram of a ٢٢٠ kV transformer bay with protection

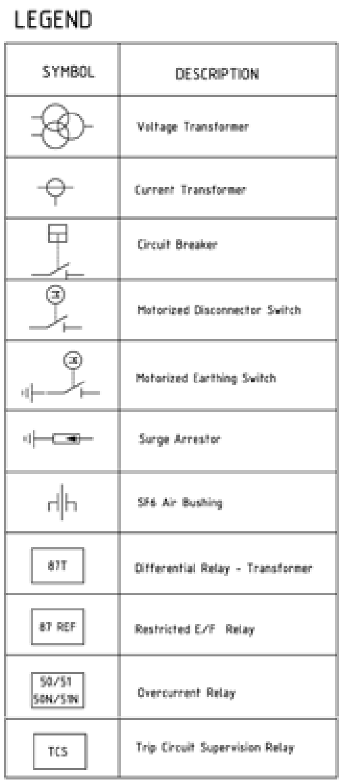


Figure ٢: Description of symbols used in Figure ١.

Oil conservator are equipped with the equipment showed in Table ٢ [٢].

The types of protection in Table ٢ are used with different schemes de- pending upontheratings of the transformer and fault levels. Inorder to plot the protection schemes, we have different codes for different type of protection called ANSI device numbers or ANSI codes, Figure ١.

Figure ١ shows typical single line diagram for the ٢٢٠ kV sub- stations in which the transformer is protected by differential protection along with overcurrent and restricted earth fault protection.

Figure ٢ shows the description of symbols and codes used in Fi- gure ١, types of protection devices / IEDs and other switching / measuring devices.

Description of codes

A. Current protection functions ANSI

٥٠/٥١ – phase overcurrent

Three-phase protection against overloads and phase-to-phaseshort-circuits.

ANSI ٥٠N/٥١N or ٥٠G/٥١G – earth fault

Earth fault protection based on measured or calculated residualcurrent values:

- ANSI ٥٠N/٥١N: residual current calculated or measured by٣-phase current sensors
- ANSI ٥٠G/٥١G: residual current measured directly by aspecific sensor.

Table ٢: Protection used for ratings above ٥ MVA

List of protection types used for transformers of rating above 5 MVA
Gas detector relay (Buchholz relay)
Overload protection (thermal relays or temperature monitoring systems)
Overcurrent protection
Ground fault protection
Differential protection
Pressure relay for tap-changer compartment
Pressure relief device

B. Differential protection

ANSI ٨٧T – Differential

Three-phase differential protection has a task to protect particu- lar zone from difference in current which is entering and leaving from one side to another in a particular zone. The differential protection function protects the zone between the main and ad- ditional current sensors inside the protected zone between the two sets of current transformers (CT) [٥].

٤. Transformer protection types

OVERCURRENT PROTECTION

Basic principle

Fault impedance is no greater than the load impedance, therefore fault current is greater than load current. Over current relays sen- se fault current and also overload current. When the fault current is above a certain level called the pickup level, relays pick up anddisconnect the circuit.

Types of over current include:

- overload current
- short circuit current

Three-phase differential protection has a task to protect particular zone from difference in current which is entering and leaving from one side to another in a particular zone

Overload current

We exercise different characteristic curves to cover possible over- loads during shorter periods of time, e.g. during through faults. Because of high currents, these stress the equipment thermally and high thermal power is dissipated. On the other hand they cannot be detected by thermal relays because there is no time fora temperature rise.

While the high stage overcurrent operates as a back-up protec- tion and the differential protection is the main protection, the low stage with its characteristic curve protects from possible overloads during through faults and is not a back-up protection. If there is a through fault just behind the transformer, the dif- ferential protection would not trip. Yet, the transformer would be overloaded and if the circuit breaker behind the transformer does not trip, then the whole transformer must be disconnected.

Short circuit current

This includes phase faults, winding faults and earth faults. Usu- ally short circuit current is ٥ to ٢٠ times the full load current, therefore fault clearance is desirable.

Characteristic curves

IEC ٦٠٢٥٥ defines a number of standard characteristics as fol-lows, Table ٣:

- Standard Inverse (SI)
- Very Inverse (VI)
- Extremely Inverse (EI)
- Definite Time (DT)

Table ٣: IEC Inverse Characteristic Equations

IEC Inverse Characteristic Equations		
IEC SI (Standard Inverse)	IEC VI (Very Inverse)	IEC EI (Extremely Inverse)
$t = TMS\ x \frac{0.14}{(I/_{Is})^{0.02} - 1}$	$t = TMS\ x \frac{013.5}{(I/_{Is})^{1} - 1}$	$t = TMS\ x \frac{80}{(I/_{Is})^{3} - 1}$

In protecting power transformer, overcurrent relay is typically used as a backup protection following Inverse Definite Mini- mum Time (IDMT) curve with coordination of other relays.

Where,

TMS = time multiplier setting (relay operating time can be variedby varying the TMS setting)
Is = set current value
I = measured current
valuet = operating time
(sec)

A Earth fault protection

Earth fault is the most frequent occurring fault in the power sys- tem. In HV/EHV networks an earth fault manifests as a flow of current through neutral/return conductor of the grounded sys- tem. Although phase fault relay responds to earth faults, such protection lacks sensitivity. To overcome this, separate earth fault relays are used which respond to residual component of current and thus are unaffected by the unbalanced load conditions. Since neutral earthing resistance is generally used, low settings are re-quired.

Earth fault is the most frequent oc-curring fault in the power system. It manifests as a flow of current through neutral/return conductor ofthe grounded system

There are two types of earth fault protection:

١. Restricted

٢. Unrestricted

Restricted earth fault (REF)

Under normal conditions and by application of Kirchhoff's laws the sum of currents in both current transformers (CTs) equals zero. If there is an earth fault between the CTs then some current will bypass the CT's and the sum of currents will not be zero. By measuring this current imbalance, faults between the CTs can ea-sily be identified and quickly cleared.

Fault detection is confined to the zone between the two CTs hence the name 'restricted earth fault'.

A restricted earth fault (REF) is an earth fault from a restricted/localised zone of a circuit. The term 'REF protection method' me- ans that earth faults outside this restricted zone are not sensed. REF is a type of 'unit protection' applied to transformers or gene- rators and is a more sensitive differential protection.

REF protection is fast and can isolate winding faults extremely quickly, thereby limiting damage and consequent repair costs. If CTs are located on the transformer terminals only the winding is protected. However, quite often the secondary CT is placed in the distribution switchboard, thereby extending the protection zone to include the main cable.

Without REF, faults in the transformer star secondary winding need to be detected on the primary of the transformer by the re- flected current. As the winding fault position moves towards the neutral, the magnitude of the current seen on the primary rapid- ly decreases and could potentially not be detected (limiting the amount of winding which can be protected). As the magnitude of the currents remain relatively large on the secondary (particular- ly if solidly earthed), nearly the entire winding can be protected using REF. As it is essential that the current in the CTs is balan- ced during normal conditions (and through faults), historically REF has been implemented using high impedance relays. CT's have also been specified as matched pairs and the impedance of leads/wires and interconnecting cables has had a large influence on the functioning of the relay. Measurement errors associated with these issues have been responsible for nuisance tripping and the system can be difficult to commission. This may be the reason some people avoid the use of REF. Recent advances in numeri- cal relay technology have all but eliminated these issues, making the implementation of REF relatively easy, ensuring no nuisance tripping and simplifying commissioning [٦].

During normal condition, the current with no interruption flows through the protected equipment and the net current through the relay is zero

Unrestricted earth fault

It responds to earth fault from any point in network. This protec- tion is used to sense earth fault at any point in the system.

In the absence of earth fault the sum of three line currents is zero hence the vector sum of three secondary currents is also zero:

$I_{as} + I_{bs} + I_{cs} =$ ٠

$I_{rs} =$ ٠,

Where,

I_{rs} = residual current

$I_{as} + I_{bs} + I_{cs}$ = per phase currents (red, yellow, blue)

In case of a fault, residual current is not zero. The earth fault relay is connected in such a way that residual current flows through it if the relay operates above pickup level, as in Figure ٣.

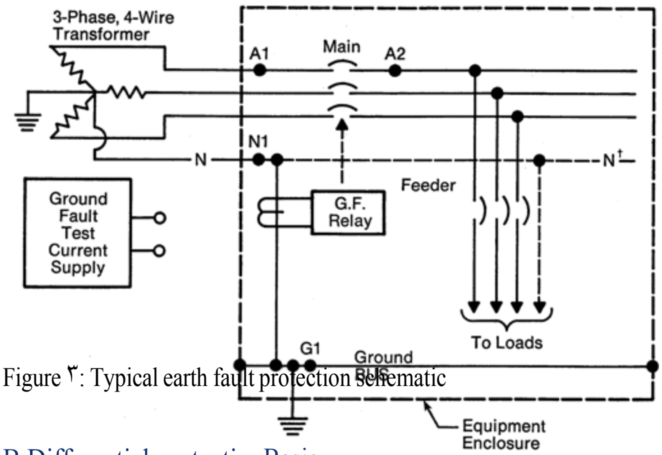


Figure ۳: Typical earth fault protection schematic

B Differential protectionBasic

principal

It is based on the principle of Kirchhoff᾽s current law, i.e. by com- paring the secondary current of the current transformers located at each end of the protected equipment. During normal condi- tion, the current with no interruption flows through the protec- ted equipment, and the net current I_n through the relay is zero. The figure shows a scheme of differential protection. Let us assu- me *I*١, *I*٢ and *I*٣ are the three respective secondary currents of the relay in case of normal operation. If any fault occurs outside the boundary defined by current transformers, the relay would not operate. But if it occurs in the region bounded by the two current transformers, the relay will give the signal to the circuit breakerto trip the circuit.

The differential protection designed for the transformer is of a percentage type where restraint coils are employed.

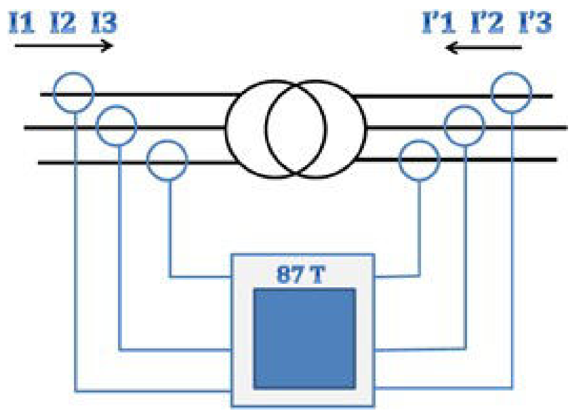


Figure ٤: Transformer differential protection schematic

Restraining coils are also called bias coils. Due to the difference in the magnetising currents of the high and low voltage current transformers, the current through the operating coil will not be zero even under normal loading conditions or external fault conditions. Therefore to provide stability on external faults bias coils are provided. To obtain the required amount of biasing, a suitable ratio of the biasing coils with restraining coils needs tobe provided.

Following points while designing a differential protection sche-me for a transformer must be considered:

- There is always a certain amount of unbalanced current in the operating coil of a transformer differential relay because the current transformers are not ideally matching due to the turns ratio of transformer and also due to the resistance ofcoil.
- Due to the requirement of magnetising current, some un- balanced current remains in the operating coil as there is no current in the secondary while the current in primary per- forms excitation.
- Inrush current does exist in transformers. Its magnitude and duration depends on residual field present in the core and the point on the ac cycle where the re-energisation has occurred. Initially its value is ١٠ to ٢٠ times the full load current in large transformers and becomes negligible in fewminutes.
- The presence of tap changer in the transformer also adds complexities [٤].

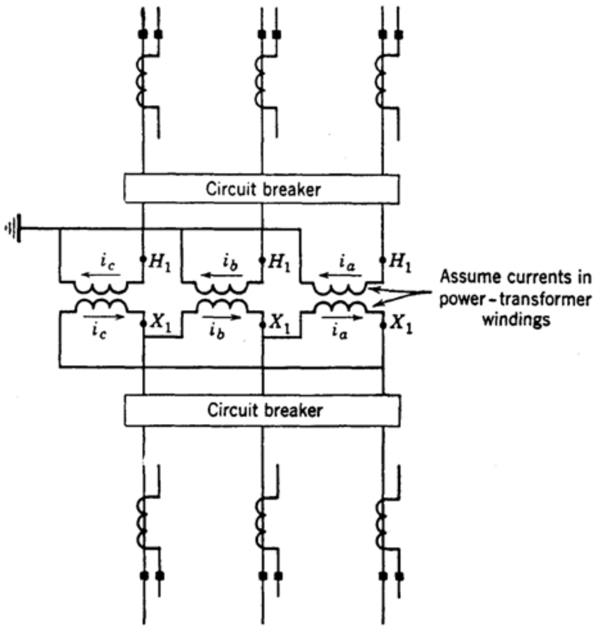


Figure ٥: Transformer differential protection - single line diagram

The presence of tap changer in the transformer causes additional com-plexities in the protection.

The scheme on the Figure ٥ shows the typical differential pro- tection for a star/delta transformer showing the connection for current transformer and relay coils.

C Bucholz relay

- Buchholz relay is a gas-actuated relay installed in oil im- mersed transformers for protection against several types of faults. Named after its inventor Mr. Max Buchholz (١٨٧٥–١٩٥٦) in ١٩٢١, relay is used to set off an alarm in case of in- cipient (i.e.slow-developing) faults in the transformer and to disconnect the transformer from the supply in the event of severe internal faults, Figure ٦. It is usually installed in the

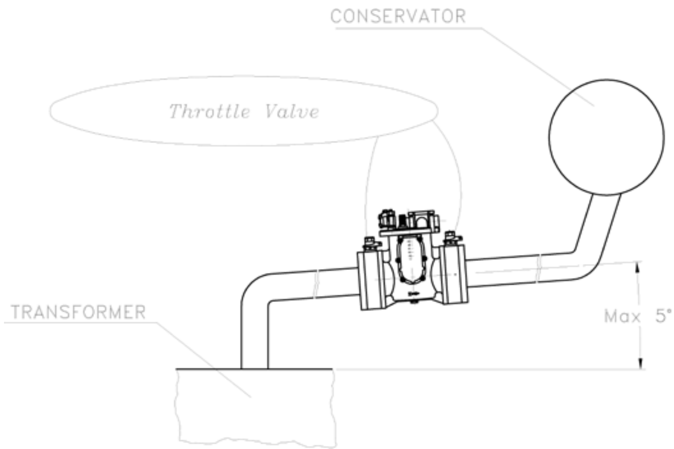


Figure ٦: Bucholz relay fitting location

pipe connecting the conservator to the main tank.

- It is a universal practice to use Buchholz relays on all oil im- mersed transformers having ratings in excess of ٧٥٠ kVA. The Buchholz relay is a protective relay for equipment im- mersed in oil for insulating and cooling purpose, Figure ٧ and Table ٤.

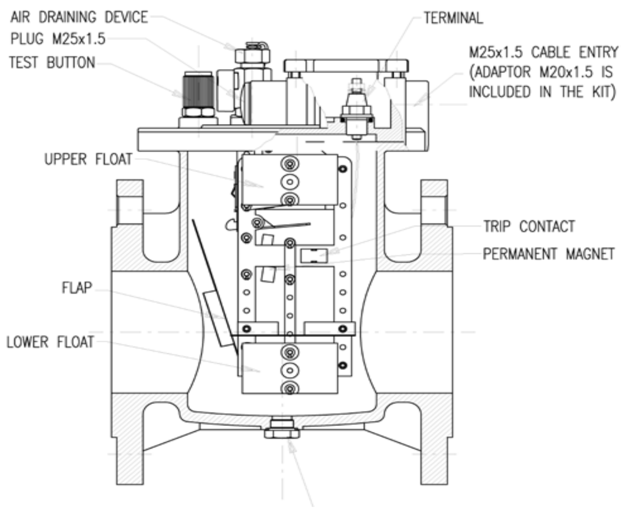


Figure ٧: Bucholz relay

٥. Monitoring of transformer

A Winding temperature indicator

The winding is the component with the highest temperature within the transformer and is subject to the fastest temperature increase as the load increases. In order to have control of the temperature parameter within the transformer, the temperature of the winding as well as top oil, must be measured. An indirect system is used to measure winding temperature, since it is dan-gerous to place a sensor close to the winding due to the high vol-tage. The sensor in the winding temperature indicator directly measures the CT current and uses the algorithms associated with IEC ٣٥٤ to provide accurate winding temperatures for all cooling gradients via the feedback system, Figure ٨.

Figure ٨: Winding temperature meter

B Oil temperature indicator

The oil temperature indicator (OTI) measures the top oil tempe-rature. This is a specific measurement location at the top of the transformer. Its temperature is used for the transformer controland protection, Figure ٩.

because if the oil level falls below the level of the radiator inlet, flow through the radiator will cease and the transformer will overheat [٥].

Figure ١٠: Oil level meter

Conclusion

This article explains the basic information and provides an over- view on different types and schemes of transformer protection. The protection schemes so far designed can successfully protect the transformer and mitigate the risk of enormous destruction that can be caused by transformer explosion; protecting major and expensive power system equipment and human life. The engineers and researchers are still working on utilising the new technologies for protecting transformers more successfully and more cost effectively.

Figure ٩: Oil temperature meter

C Oil level indicator

An oil level gauge is required so that the correct oil level can be maintained, Figure ١٠. There is usually a mark on the gauge that indicates the ٢٥ °C level, which is the proper oil level at that tem- perature. Maintaining the proper oil level is extremely important

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