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A Literature Review: Traditional and Advanced Protection Schemes of Power Transformer

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Abstract— Power transformers perform a pivotal role in a power system network in ensuring reliable power supply to electricity consumers. This paper contributes the concept about different types of transformer protection so that will be more helpful for investigating the protection system of the transformer. In this Paper, an effort is made to put together developments in the protection of the transformer. Efforts have been made to cover all the techniques and philosophies used to that end. The article includes the most recent techniques and traditional techniques of the transformer. There are many important parts installed in the transformer which is very costly so these have to be safe in an abnormal condition. Transformer performs a great job in the power system to change voltage and current level so proper protection for the transformer is important to maintain reliability in the system. Usually, a well-designed transformer protection system provides a great life without any uninterrupted power supply. To increase life, efficiency, overall performance then reduces stress on the transformer is the only way so this protection system help here to observe those things properly.

Keywords— Power Transformer, Fault statistics, Fuzzy set method, Artificial Neural Network Approach Overcurrent protection, Differential protection, Inter-turn fault, Earth-fault protection, Traditional method of protection.

I. INTRODUCTION

The function of protective relaying is to initiate the prompt removal of the faulty element from service in order to minimize the damage to the system. Rockefeller first presented the role of digital computers in 1969. Later on, with the development of the microprocessor in early seventies, its role in digital protective relays has become a very attractive option. Among the various elements of the power system, the power transformer is one of the important elements. Due to its importance, its protection needs to be fast and reliable. Hence, significant work has been done in this area [1-2].

The transformer is part of the power system so proper protection system is important for the transformer. Generally, back up protection should be required for protected transformer because if the relay or circuit breaker failed to operate then, there is the chance of the whole transformer can be damaged so this is not economical. Transformer operation can be classified as follows: Normal operation, magnetizing inrush, over-excitation, and fault condition. For the first three operating conditions, the relay should not operate, but for any fault, the relay must operate. Cost and weight of the transformer are high and we cannot transport the transformer to the maintenance department to clear fault clearing purpose so protection system performs a great role here to avoid this condition [2] [32-34].

II. FAULT STATISTICS

Table 1 classifies failures statistics for six categories of faults which is given by IEEE guide in Protective relay system for Power Transformer. Mostly, due to winding and tap changer near about 70% faults occurred in the transformer and other fault occurring possibilities are quite low as possible so winding and tap changer is the main reason to cause the fault in the transformer [28]. So transformer protection under abnormal condition is great challenging part to engineer. Loose connections are involved as the initiating event as well as insulation failures. The different category includes CT failure, external faults, overloads, and damage in shipment. These failures can be identified by sophisticated online monitoring devices (e.g. gas-in-oil analyzer) before a serious incident occurs [24-26].

Due to these failure rate observation, proper transformer protection gear is important to maintain continuity of the power supply. So this paper represents various types of the transformer protection system.

Table 1 Failure rate [27]

Name of Faults	1955-1965		1975-1982		1983-1988	
	Number	% of total	Number	% of total	Number	% 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	21	6	101	26
Total	262	100	1127	100	389	100

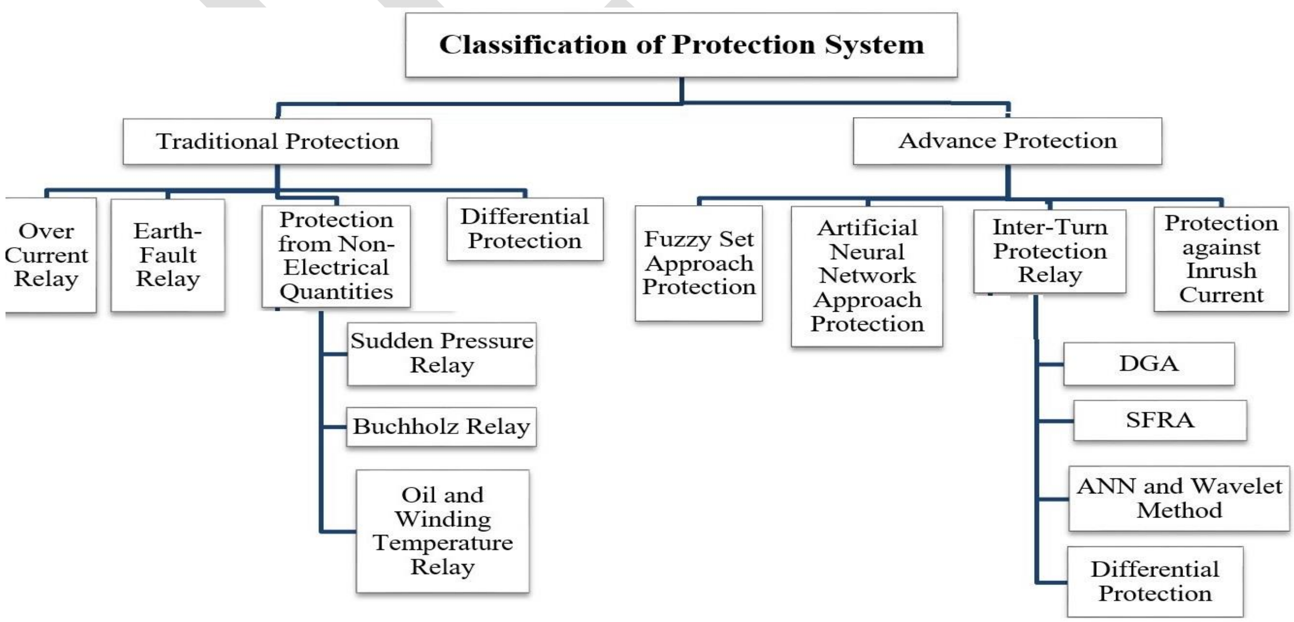
III. CLASSIFICATION OF TRANSFORMER PROTECTION RELAY

In general, the faults occurred in the transformer due to weakening or failure of insulation. This insulation failure causes increases in temperature of the transformer oil and this lead to making the poor performance of the transformer. So for that purpose temperature monitoring system is provided for transformer oil. Sometimes due to a transient situation over voltage and over current occurred so for that purpose overcurrent relay and differential protecting system used [1-3]. There are many faults occurred, but some abnormal fault is not making a big issue in the transformer like magnetic inrush current, over fluxing, low oil level.

Although these abnormal conditions are not faults in the transformer. So for these faults, no protective gear is employed. But one important thing is that if the abnormal fault is prolonged for a long time then it makes a big problem in the transformer [2]. The most important protection system chart is given below. Always this protective gear should be working properly otherwise it will make a big problem in the transformer after the occurrence of the fault [2] [30].

A. ADVANCED PROTECTION SYSTEM

1. Fuzzy Set Approach for Transformer Protection



Fuzzy Set theory concept is firstly founded by Zadeh scientist in 1965 for dealing with uncertain and ambiguous properties of events. And for power system protection fuzzy set concept firstly used in 1979. Accordingly, fuzzy set theory can be counted as a generalization of the standard set theory. In fuzzy set theory, the association of the element can be continuously changed. Since fuzzy logic uses heuristic knowledge, expert knowledge, and experience, it is a very beneficial mathematical medium to solve decision-making problem. So it is a very powerful weapon to express quantitatively uncertain values and the relation between them [4].

The transformer is a critical ingredient of the electrical power system. To magnify the fault detection sensitivity of traditional percentage differential current relaying algorithm, fuzzy logic strategies are used. Fuzzy inference is a method that makes a decision in parallel [4-5]. Because of this property, there is no data destruction during the process and so final fault detection will be far more precise than that of traditional relaying techniques. Fuzzy logic uses linguistic variables rather than numerical variables. The process of converting a numerical variable (crisp variables or real number) into a linguistic variable (fuzzy number) is named as a Fuzzification. Fuzzification performs an extraordinary role in dealing with uncertain information, which might be objective or subjective in nature.

Researchers developed differential power transformer protection after 1990 using a fuzzy logic concept. The fuzzy logic approach can also be with conventional DGA method for fault detection and decision-making. So this paper also shows an improved method for fault detection of transformer parallel with the traditional method [6]. This method gives the self-adjusting characteristic and this will helps in detection faults in the transformer. It has been claimed that the methods are able to detect incipient faults. To make more powerful a combined method of multi-criteria, fuzzy set and wavelet-based method were presenters by Jiao et al [35]. This article summarizes fuzzy based algorithm consisting flux-differential current derivative curve, harmonic restraint, and percentage differential characteristic curve [4].

The following advantages shows the fuzzy logic based approach:

- The fuzzy based relaying algorithm is not allowed to operate unnecessarily operation of the relay in the event of magnetizing inrush with low second harmonic component and internal faults with the high second harmonic component. So these results enhance accuracy and robustness against the change of condition in the power system.
- Due to this fuzzy algorithm relay obtain high sensitivity to detect fault detection and operate with average tripping time of about 3/4 cycles. Therefore, the method is reliable and speedy.

2. Artificial Neural Network Approach Protection

The second most dominant mathematical tool of recent time is an artificial neural network (ANN), which attracts the researcher's to tackle the transformer protection difficulty [7]. The characteristic feature of the ANN is that it considers the accumulated knowledge acquired during training and responds to new events in the most proper manner given the experiences gained during the training process. The model of the ANN is prepared according to network architecture, transfer function, and learning rule. The architecture is concluded by corresponding weights and connection scheme. The objective of the training process is to adjust all ANN weights to obtain minimal deviation between the target and calculated ANN outputs in relation to the mean value of all input samples [7] [9].

The criterion function for the sum square error is minimizing according to the standard gradient procedure. The effectiveness of ANN depends on the quality of the training procedure. In ANN, the waveform analysis method is used to train the neural nets. To implement the neural network, the following three difficulties arise, i.e., a set of training examples must be defined, the multilayer perceptron is small enough to allow the convergence of weight, and the input must be defined and coded with the core so that they are representative of the events to be identified [7] [28] [36].

The following events have to be considered in applying an ANN approach:

- No fault situation,
- Energization,
- External fault,
- Turn to turn internal fault, and
- Turn to earth internal fault.

The relay should operate in the last two situations, but it should identify all the above conditions. The artificial neural network is used for fault diagnosis of the power transformer, and some recent studies report that ANN is used as a classifier along with dissolved gas analysis method, and determined very good results [8]. The nature of the fault is judged by the amount of the gas decomposed from oil present in the tank. In concern of fault diagnosis of the power transformer, recent investigations show that the ANN and expert system tools are the decision-making elements. The performance of trained ANN is tested successfully for the classification of numerous cases. ANN is implemented in the LabVIEW environment for the real-time application [31].

3. Protection Against Inrush current

The transformer is a critical ingredient of the electrical power system. Usually, by utilizing differential protection transformers are being protected. But whenever a transformer is energized, sometime malfunctioning may take place in the differential protection due to inrush current. Some techniques are used to depreciate the fault [11]. Those techniques are like per-phase method, the cross-blocking method, Percent average blocking method, and harmonic sharing method. Then the fuzzy logic system has been adopted to divide the internal fault from magnetizing inrush current. After that, differential protection has been adopted which was based on the wavelet packet transform. Then Mathematical morphology based inrush blocking scheme has been used [10] [29].

In this paper, the comparison is made between per-phase method, cross-blocking method, percentage average blocking method, harmonic sharing method, fuzzy logic, wavelet packet transform based technique and Then Mathematical morphology based inrush blocking scheme [29] [35]. Following methods shows the different protection schemes against magnetic inrush current:

a) Per-Phase Method

The per-phase method is the uncomplicated and traditional method to restraint harmonics. In every phase, the restraint algorithm is parallel and independent. In the Per – Phase Method, this criterion applies to each phase separately. In each phase, the residual flux is different. So in each phase, the magnitude of 2nd harmonic will be different. This method works on the threshold value. Thus, if the 2nd harmonic content is low in a phase while energizing, the differential protection may trip. That's why this technique is very reliable but not very secure [10].

Since different residual flux belongs to each phase energization of each phase has been done at a different angle, every phase will have a different level of harmonics. When the ratio value of the second harmonic for a specific phase is greater than a preset level, the percent differential operation will be inhibited on that phase. There is a possibility of having a ratio of low second harmonic for each phase at the time of transformer energization. If there is a small ratio of the second harmonic in a phase during differential operation, the undesirable the trip may occur in the three-phase transformer [10].

b) Cross-Blocking Method

This technique is very highly correlated with Per–Phase Method, the single dissimilarity is that the signal which is restraint from a phase will restrain differential operation for all another phase. Differential protection will trip at above the pre-set value of the second harmonic for other phases also. In the case of the symmetrical fault, this technique works properly. But if there is a single unsymmetrical fault, the differential protection will trip [10].

This method prevents the possibility of erroneous tripping by improving the security because this technique allows the phase with a ratio of low harmonic to be cross-blocked by a phase with a higher ratio. The insulation usually bears huge mechanical stress at the time of energization and the inrush current is usually a few times greater than the rated current. This cross-blocking technique is well secure but not so trustworthy. Two-out-of-three restraint method is similar to a cross-blocking method. In this method, blocking of differential operation needs minimum 2 phases to detect the adequate level of harmonics. But this method also has the same basic drawback of the simple cross-blocking technique [10].

c) Percent Average Blocking Method

For percentage average blocking method, harmonic ratio means the average of the 2nd harmonic ratio of three phases the security of the differential protection has been enhanced by this percentage average blocking method. So this method is more secure than the two-out-of-three method and cross-blocking method. If there is a large harmonic ratio in the remaining phases, it is highly possible that the differential operation will be restrained owing to a true single-phase fault during energization. There arises a concern relating to the dependability in the differential protection [10].

d) Harmonic Sharing Method

A single harmonic signal has been created by summing all the magnitudes of all 2nd harmonics from three phases. The resultant value is shared to calculate the ratio of 2nd harmonic for every phase. If there is even a very low 2nd harmonic in any phase, the shared harmonic calculated from will be large, and the 2nd harmonic ratio will become larger enough to restrain the differential protection system from maloperation. If an internal fault is found in a phase at the time of energization. If the value of the fundamental current surges very high the consequence is a low harmonic ratio. Therefore there is less chance to arise a problem from a faulted phase. So the tripping of a three-phase transformer will occur during an internal fault. The security against maloperation has improved with the help of this harmonic summing technique [10].

4. Inter-Turn Fault

$$1.0 \le \frac{CH_4}{H_2} < 3,\ \frac{C_2H_6}{CH_4} < 1.0, 1.0 \le \frac{C_2H_4}{C_2H_6} < 3,\ \text{and}\ \frac{C_2H_2}{C_2H_4} < 0.5$$

Protection

Among the detection of numerous faults in the transformer detection of winding inter-turn fault is crucial since its effect is not easily comprehensible at the lower magnitude in the signatures of terminal voltages and currents. Among these faults, winding inter-turn fault is challenging to monitor and detect, especially at a lower magnitude of the fault current. As per the survey of the faults in a transformer is calibrated, which shows that 19% of the total faults occur in the windings [12] [39].

Fig. 1 shows the schematic of winding inter-turn fault in the three-legged transformer. The fault is shown on R-phase of the primary winding by connecting fault-impedance (Z_f) across the short-circuited turns. At a lower magnitude of fault-current (I_f), the terminal voltages and currents are less sensitive to If since it distributes through the short-circuited turns through Z_f [13] [37].

The impedance Z_f acts as a supplementary load on the winding, which performs as an autotransformer. The winding current supplies additional current drawn by Z_f. However, if the severity of I_f is not important, the increase in the winding current cannot be observed. This poses the difficulty in the detection of winding inter-turn fault, especially at a lower magnitude of If. The fault is mostly launched by insulation failure of the turns in the vicinity to each other [13].

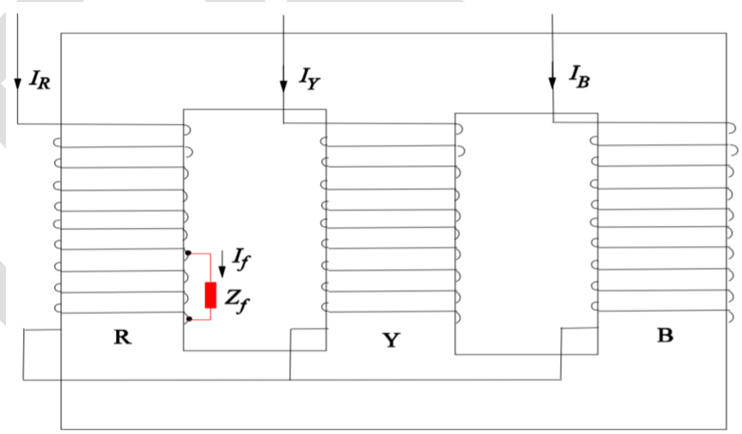


Fig. 1 Schematic for inter-turn fault in transformer [13]

There are various methods available to check the winding condition. The following subsection shows detection method for inter-turn fault for the transformer:

a) Dissolved Gas Method (DGA):

These are a very popular diagnostic method. The transformer winding and oil are made of cellulose and mineral oil. Whenever any fault or thermal stress or electrical stress occurred on them then some amount of gas is produced. These observed gas we take it as the sample for DGA analysis and comparing to these observed gas to normal condition gas. If this gas is found in the range of 0-500 ppm (parts per millions) then the transformer can be said to be the normal condition [13] [38]. The mixture of individual gas compositions is used to predict the actual fault. The composition of Ethane is found to be more than 35 ppm then observed data is suffering from the localized overheating problem. To check the presence of circulating current then the flowing composition is required in the gas.

b) SFRA Scheme:

Sweep Frequency Response Analysis (SFRA) is an effectual and sensitive method to estimate the mechanical integrity of core, windings, and clamping structures within power transformers by calibrating their electrical transfer functions over a broad frequency range. SFRA is a certified method for frequency measurements. SFRA is one of the best and accurate methods among all method [13].

In this method from one side of winding we apply pulse wave and in another side of the winding, we observe frequency response for the given input. And analyse these results there are three methods:

- Time-based – current SFRA results will be compared to past results of the same unit.
- Type-based – SFRA of one transformer will be compared to an identical type of transformer.
- Phase comparison – SFRA results of one phase will be compared to the results of the different phases of the same transformer.

If any change observed in the output frequency response then it clear that transformer is suffering from some fault condition. For each part of the transformer, the different frequency range is allowed. So observed response should lie on that particular range [13].

c) ANN And Wavelet Method

Artificial Neural Network (ANN) and Wavelet transform is advanced technology used for transformer diagnostic. ANN technology is also used in conjunction with the SFRA technique.

In this technique, we compare winding transfer function at a healthy and faulty condition case and their difference is delivered to the ANN input. ANN is prepared for various differences in the winding transfer function and then, it performs as a decision-making tool to identify the fault in the winding. A Maxwell Hat Wavelet (MWH) or Morlet Wavelet is convoluted with the detecting signal of the faults. Their convolutions with the neutral current of the transformer under the impulse test can demonstrate an indication of the inter-turn fault [13-14].

ANN scheme for detecting inter-turn fault can deal with the complex situation and it is robust with respect to the missing data. In order to use ANN for detecting inter-turn fault then a large number of fault cases needs to be simulated or practically performed to train the neurons. For ANN and Wavelet method requires a large number of processors and instruments [14].

d) Differential Protection Scheme

The differential relay can detect internal faults easily. The principle of Differential Protection scheme is simplistic conceptual technique. The basic block diagram is shown in figure 9. The differential relay actually distinguishes between primary current and secondary current of the power transformer if any unbalance noticed in between primary and secondary currents the relay will actuate and trip both the primary and secondary circuit breaker of the transformer. Differential protection is based on balancing current on both sides of the winding. As per classical method, primary and secondary phase current are measured, converted to common base value and compared to compute differences in the currents [13].

The Difference is observed continuously as a parameter for the fault conditions. Under the normal operating condition fault current is small and in the abnormal condition, it becomes too high so that can be detected by the relay [20-21]. However, they achieve a larger value during the internal faults, which recognizes them as the detection parameters for winding inter-turn fault. However, the sensitivity of this method for winding-failure detection depends largely on the accuracy of measurements by the instrument transformer [25].

Table 2 Summery of Inter-turn Methods [13]

Methods Name	Advantages	Limitations
DGA	Detection of any abnormality at incipient level	Expensive, Not suitable for air-cooled transformer, Ambiguity in the analysis
SFRA	Capacitive effect can be detected at high frequency	Needs expert’s opinion, Require additional sophisticated instruments
ANN And Wavelets	Detect minute fault during impulse test robust for missing data	Based on neutral current not always accessible, Memory and computation intensive
Differential Protection	Classical and Robust method	Sensitive to instrument transformer

B. TRADITIONAL PROTECTION SYSTEM

i. Non-Electrical Protection

In order to preserve the transformer against incipient fault, the special protective gear arrangement is required. Overheating, the over fluxing or sudden increase in pressure that outcomes show incipient faults. The cause for this type of is mainly due to deterioration of insulation. These faults introduce arcing to the transformer which can be detected by the protective relay. This non-electrical protective consist of three relay:

a) Buchholz Relay

Buchholz relay is used for detect fault in the transformer with help of heating monitoring. This device detects the small produced gas in the oil by low-energy arcs, insulation decomposition, overheating. This relay also detects heating due to increased power transferred, increased ambient temperature, high eddy current between lamination, arcing, overloading [15]. Buchholz relay is connected between conservator and transformer tank.

Whenever any fault occurred in the transformer then the temperature of the oil is increasing then on that principle Buchholz relay works. Location arrangement can also be displayed in figure 2 and the operation principle of this relay is very simple. Construction is given below figure 2. Relay is mounted in such way that this arrow point towards the conservator and is at an angle of 5 degrees. There are multiple ways to analyze fault in the transformer. But by observing oil temperature method also one the reliable method among another method [25-26]. Whenever a fault has occurred then production of gas is started in the oil. There are two mercury switches used in the relay and one belongs to trip alarm switch and second is to trip the circuit breaker.

Following condition is responsible for activation of the alarm circuit:

i. Oil leakage
ii. High resistance inter-turn faults or other winding faults
iii. Faulty joints
iv. Failure of core insulation
v. Formation of hot spots on the core due to the short circuit of laminated insulation

Mainly to trip mercury switch major internal fault is initiated in the transformer. Following condition is responsible for activation of the trip circuit:

i. All severe winding faults (solid inter-turn or turn-earth fault)
ii. Fall in the transformer tank oil resulting from either continues decomposition of oil due to higher operating temperature or faulty sample collection tap.

In normal working condition, these switches are in open condition and they mounted with a 40-degree angle. Whenever any fault has occurred then in that condition these mercury switches is shifted 40- degrees to the horizontal state position. When the fault is initiated then bubbles are formed in the transformer oil tank and then it will go towards buchholz relay through pipe. Initially, the severity of fault is less so limited quantity of bubbles is formed in the oil [15].

After entering bubbles in the relay zone, it will try to rotate that alarm mercury switch in horizontal position. When alarm mercury switch circuit is closed then it sends the signal to monitor engineer transformer is under small fault condition zone. If fault severity increases further then the trip circuit is closed then from this necessary action has been required to minimize that fault as soon as possible. This switch normally will operate a circuit breaker to isolate the apparatus before the fault creates additional injury [25].

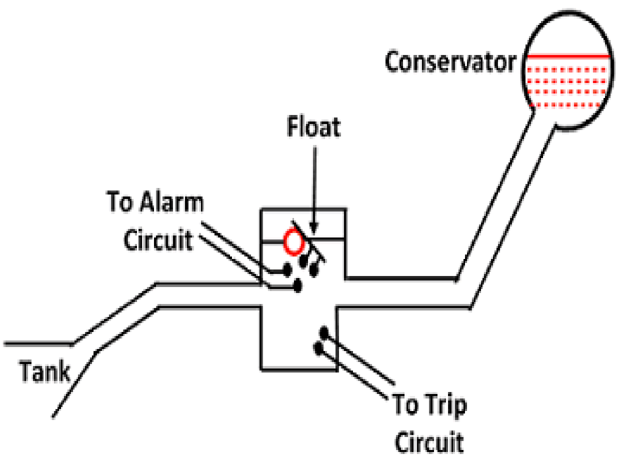


Fig. 2 Arrangement of Buchholz relay [25]

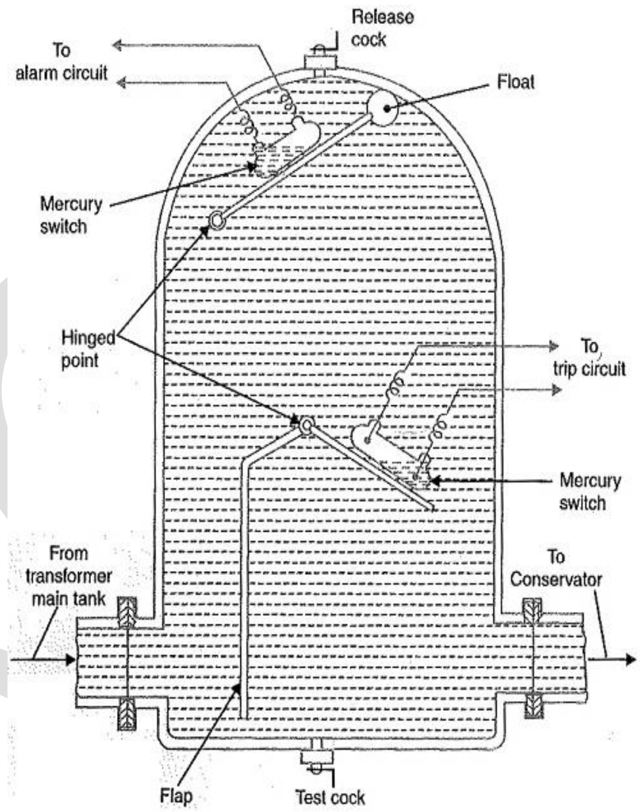


Fig. 3 Construction of Buchholz relay [25]

b) Sudden Pressure Relay

The gas pressure relay facilities the protection of a transformer merely in conjunction with a simple differential relay. Main advantages of this relay it will perform the stable operation against the inrush current. This relay can be used as the back up the protected relay for Buchholz relay. This relay operates immediately when any large production of gas in the transformer tank. The working principle for this type of relay is the rate of rise of the gas in the transformer [16-17].

Whenever any high current is passing through winding then heat is generated. So that winding heat is responsible for increases oil temperature, introduce arcing in the oil. So it will result in increases pressure in the transformer oil. A sudden increases gas pressure can be detected by a sudden pressure relay [25]. This type of relay is installed at the top of the oil-filled transformer. It performs two functions and these detect the slow accumulation of gases, providing an alarm after a given amount of gas has been collected [16].

A typical transformer gas relay consists of two chambers, each giving a distinctive function. It reacts to a sudden pressure change that accompanies a high rate of gas production. A simplified sudden pressure relay is shown in figure 4. The relay arrangement consists of a gas accumulation chamber installed directly over a pressure chamber. The accumulation chamber accumulates slowly produced gases. A float positioned in this partially oil-filled chamber moves as the gas volume increases. It operates an alarm switch when the amount of gas collected touches a particularized level [16-17].

Operating time of this relay is varies over large span depending upon the rate of gas formation. Design of this relay can be made such way that it can operate at dynamics pressure changes. The main difference in buchholz relay and sudden pressure relay is, buchholz relay can handle light internal faults and pressure relay can handle heavy internal faults. This type of relay is suitable for above 5 MVA rated transformer [16-17] [25-26].

Only one drawback of pressure relay is it can operate whenever high current is passing through the winding. Due to this disadvantage, some user prepares it for only alarm purpose only.

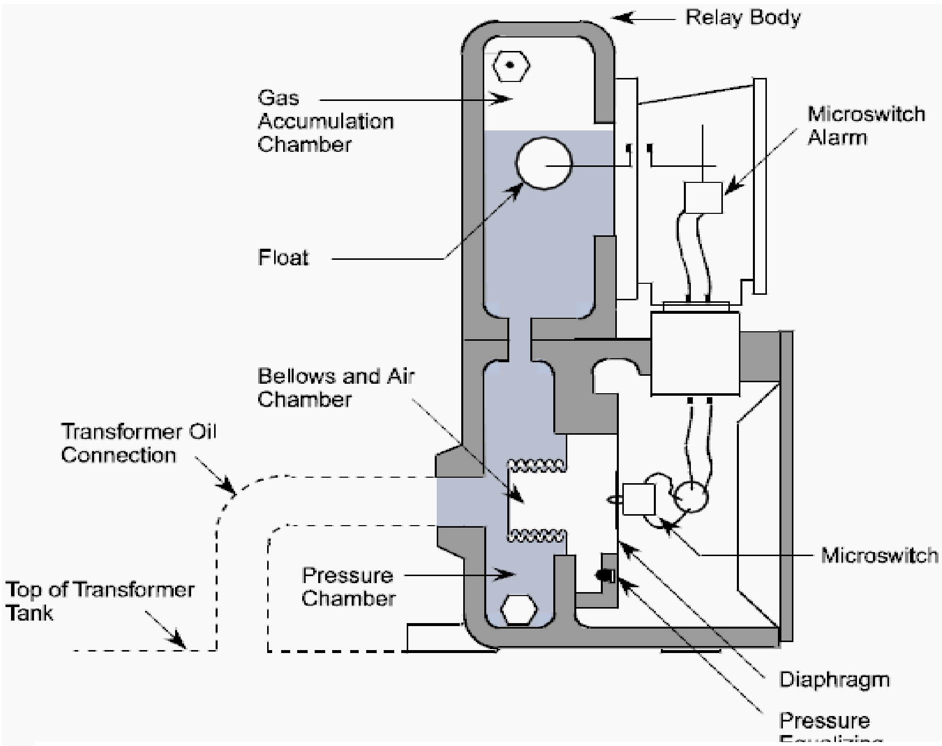


Fig. 4 Typical Sudden Pressure Relay [25]

c) Oil and Winding Temperature Relay

Transformer designed to operate for the various range of temperature depending upon the type of insulation is used in the transformer. To maintain the transformer temperature at a particular level cooling system arrangement is provided. Any abnormal temperature commencement of the winding leads to weakening of insulation either between the turns or from turn to the core. These hot spot should be carefully observed and timely inspected because it will leads to a major fault in the transformer [25].

Sometimes the resistance temperature detector (RTD) is used to detect hot spot the temperature of the winding. The temperature information from RTD is given to temperature scanner so temperature scanner will display the temperature of the winding [25].

Here winding temperature is calibrated by connecting the current transformer (CT) in series with the main winding of the transformer. The secondary side of the CT is joined to the heaters inside the transformer tank and it will represented in figure 5. The sensing bulb is situated near to heaters and will glow depending upon current will circulate in the transformer main winding. The output of the sensing bulb is connected alarm/protective gear system and temperature indicator. When the temperature of any RTD is exceeded its threshold value then the alarm protective circuit comes into the picture. Depending on alarm action, operator engineer will take the decision. If the temperature is increased further then one sensing device is used so that will open all necessary contact of the transformer [25-26].

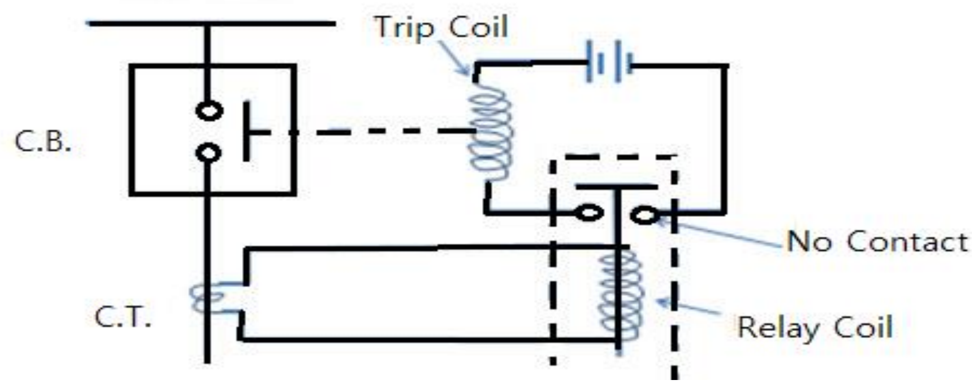


Fig. 5 Connection of WTI and alarm unit with transformer [25]

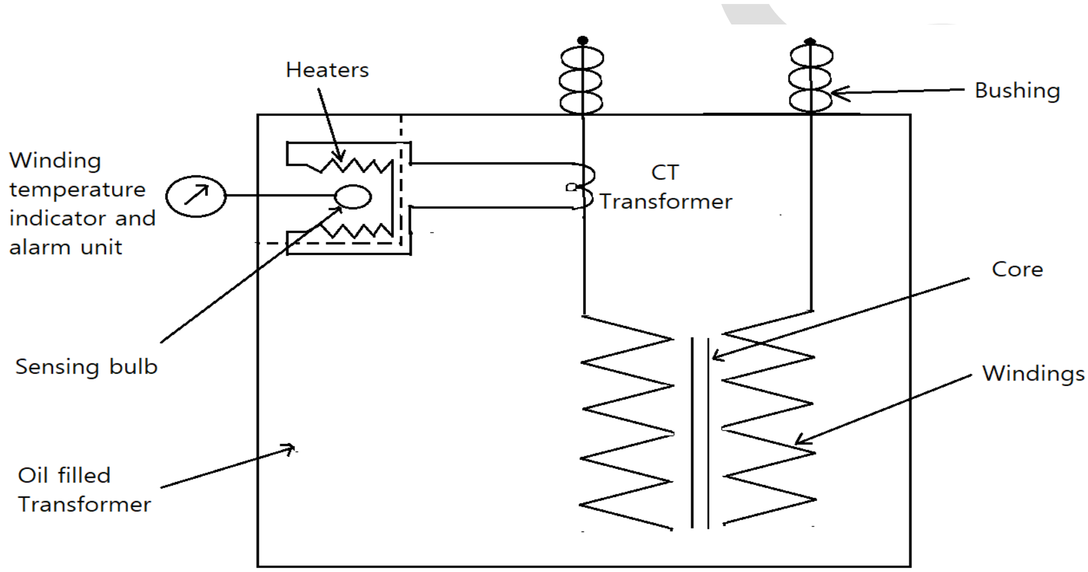


Fig. 6 Basic Overcurrent Protection System [25]

ii. Overcurrent Protection

For the small rated transformer, overcurrent relay is best for protection purpose. This overcurrent relay is suitable for 100-500 KVA transformer. This relay is also suitable for large rating transformer as the backup protection.

In general, this relay set by above normal rated current so that a short time rating is allowed by the relay. Sometimes during the low-level fault, pick up overcurrent value is not exceeded so in such cases, the instantaneous overcurrent relay will let this fault continue indefinitely. In general, this relay is set at 2-3 times above rated of the transformer. One important thing is that the pickup value of this relay is always higher than magnetic inrush current. To afford primary protection for against heavy internal faults, instantaneous overcurrent relay employed [18].

Overloaded transformer results in increasing rating size of the transformer and mechanical force are also generated. These mechanical force will try to increase winding hot spot temperature and movement of the transformer. This movement results in mechanical damage to insulation which results in hot spot temperature. Therefore, the transformer should not operate for a long time in overloading state [18].

A relay is a controlled switch. Normally, the tiny output of a Current Transformer (CT) is utilized for the relay's input. The relay typically has a shorter size and smaller rating for input. When the contact is closed, then the battery is joined to the trip coil of the Circuit Breaker and the circuit is tripped. We are basically using it as a switching transistor, to elaborate the small output of CT to the large battery voltage of Trip coil [25].

iii. Earth-fault Protection

In earth fault, the current extracted from the source terminate its path without contributing to the load. The main intention for this protection is to limit ground fault current. When the fault occurs, the short-circuit currents flow over the system, and this current is returned through the earth or any electrical equipment. This fault current degrades the equipment of the power system and also interrupted the continuity of the supply. The earth fault can be dispersed by using the restricted earth fault (REF) protection design [19].

Figure 7 represents for operating characteristics of restricted earth fault relay. High impedance restricted earth fault protection system can be employed for protecting transformer winding exactly like bus bar protection. Primary protection for high rated transformer against earth fault is achieved by differential protection relay. For small transformer differential relay is not used, so here instantaneous overcurrent relay used as a primary protection relay for earth relay [20].

A star side external faults will results in current flowing in the line current transformer of the affected phase and at the same time a balancing current flows in the neutral current transformer, hence the resultant current in the relay is consequently zero. So this REF relay will not operate for external earth fault. But during an internal fault, the neutral current transformer only offers the unbalance fault current and operation of Restricted Earth Fault Relay takes place. This scheme of restricted earth fault protection is very sensitive for internal earth fault of the electrical power transformer. The protection scheme is relatively cheaper than the differential protection scheme. Three CT's are connected together so, only one residual current is available at the output. This residual current is balanced at the secondary side of CT's. The Operating element is a high impedance relay, and a region of operation is the star winding of the transformer. The degree of protection is magnified not only because of the use of the instantaneous element but also because the entire fault current is used as the operating quantity. So this main reason this protection system is capable to detect closer value fault current near to neutral end of the winding. Operating quantity is residual current, so relay will remain stable for any fault outside its zone [25-26].

Restricted earth fault protection is afforded in electrical power transformer for sensing internal earth fault of the transformer. In this scheme, the CT secondary of each phase of an electrical power transformer are connected together as shown in figure 8. Another main advantage is it will also provide protection of transformer with the solid grounding of neutral. The REF design is quite simpler and is used alone on either side of the transformer for affording high-speed earth-fault protection [20] [25].

iv. Differential Protection

A fuse protection system quite simple and less costly, but differential protection provide several advantages over another protection system so that why we use differential protection and these are:

a) Differential protection provides faster detection as compared to another method and reduces damage due to the flow of fault current.

Fig. 7 Operating Characteristics of Earth Fault Relay [25]

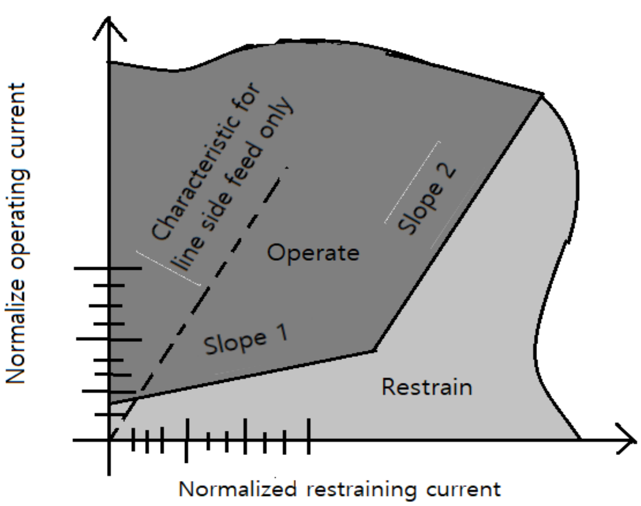
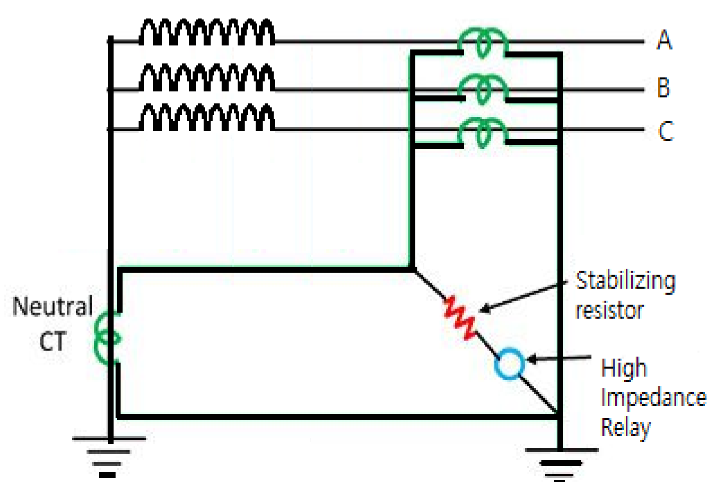


Fig. 8 Restricted Earth-fault Protection for a star winding [25]



b) The location can precisely be located by using the differential protection system depending upon the size of the protected zone.

c) Accurate faults location provides the application of automation techniques, such as rapid isolation of faulted components and restoring load.

d) The faults occur in the transformer inside the insulating oil can be identified by Buchholz relay. But if any fault occurs in the transformer but not in oil then it cannot be identified by Buchholz relay. Any flashover at the bushings is not adequately covered by Buchholz relay. Differential relays can detect such type of faults.

The principle of Differential Protection scheme is simplistic conceptual technique. The basic block diagram is shown in figure 9. The differential relay actually differentiates between primary current and secondary current of the power transformer if any unbalance noticed in between primary and secondary currents the relay will actuate and trip both the primary and secondary circuit breaker of the transformer [21-22]. Differential protection is based on balancing current on both sides of the winding. To design, the differential protection system makes the adjustment in such a way that it can compensate for the phase difference between the line current on each side of the power transformer whenever it becomes necessary [23].

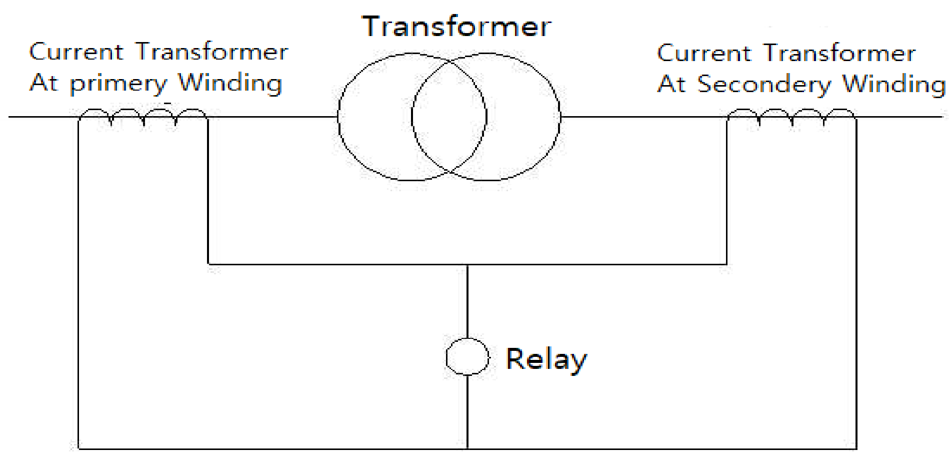


Fig. 9 Principle of Transformer Differential Protection [25]

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V. CONCLUSION

This paper represents the basic, advanced level information and provides an overview of the different type and schemes of the transformer protection. This paper contributes to different advanced and traditional based protective relay used for the transformer. There are many issues are occurred in the transformer, so to protect transformer proper protective gear arrangement is required.

The protection schemes so far designed can successfully protect the transformer and mitigate the risk of enormous destruction. The benefit of this methods is, it is an automatic protection method no manual work is required. In practice, this concept can be manipulated without any difficulty.

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