Transformer Failures, Causes & Impact

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***Abstract*—** Study of transformers, the faults that most commonly occur, the causes of these faults and their impact is conducted and discussed in this paper. The transformers that were studied were step-down transformers (11kv-220v) used by WAPDA in distribution sectors. Data about the transformer failure for the last 5 years was collected from PESCO for two locations of Peshawar district. The first region was the metropolitan area of University Town and the second was the suburb area of Ragi-Lalma. Comprehensive data mining was done to investigate the cause of failures.

***Keywords*—**Transformers, Faults, Failures, Causes, Priority Number

I. Introduction

THE Transformers are electrical devices used for energy transfer by electromagnetic induction between two or more circuits.

Like all electrical devices faults also happen in the transformers which cause failures [1]. One failure can cause many problems. A simple fault at the distributing end can cause black-out of power to the whole area. The fault can also be very dangerous as the transformers contain large quantity of oil in direct contact with high voltage components. This increases the risk of fire and explosions due to failures.

Different faults are caused by different reasons, which all have different impacts on the power system. In this paper some of the most commonly occurring failures are discussed with their causes and impacts.

This important process of stepping-up and stepping-down of voltage and current is done by Transformers present at both ends of the power transmission and distribution [11].

To avoid major line losses in power transmission over long distances the voltage is step-up to 11kv and the current is step-down as the power is transmitted to different parts of the country by long transmission lines. The losses are mathematically represented by Eq. 1:

$$\text{Losses} = I.I.R \tag{1}$$

Where I is current and R is the resistance. Longer the transmission-line more is the resistance. For this reason the voltage is kept high and the current is kept low.

After power reaches its destination through the transmission lines, the voltage is step-down form 11kv to 220v and the current is step-up [13]. It is then distributed to the consumer.

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The transformers are one of the most expensive components in this network which makes it another reason for being very important. As an important component the study of the faults and failures of the transformer is also very important.

II. Classification

A power transformer like many electronic devices faces many failures. MIL-STD-1629A standard is used to classify different faults that occur [2]. It is the most commonly used standard used through-out the world for the past 30 years.

Each fault is first classified into three categories which are further subcategorized.

The first category the faults are classified are on the basis of severity of the fault. The bigger the fault the more sever it is. Table-I shows this classification.

TABLE I
SEVERITY CLASSIFICATION FOR POWER TRANSFORMERS

Value	Description	Criteria
1	Category IV (Minor)	Primary function can be done but urgent repair needed
2	Category III (Marginal)	Reduction in ability to primary function
3	Category II(Critical)	Causes a loss of primary function
4	Category I (Catastrophic)	Product becomes inappropriate

The second category the faults are classified are on the basis of the occurrence of the fault. The more frequent the fault occurs the more sever it is. Table-II shows this classification.

TABLE II
OCCURRENCE CLASSIFICATION FOR POWER TRANSFORMERS

Value	Description	Criteria
1	Level E (Extremely unlikely)	Probability of occurrence less than 0.001
2	Level D (Remote)	Probability of occurrence more than 0.001and less than 0.01
3	Level C (occasional)	Probability of occurrence more than 0.01and less than 0.1
4	Level B (Reasonably Probable)	Probability of occurrence more than 0.1and less than 0.2
5	Level A (Frequent)	Probability of occurrence more than 0.2

The Third category the faults are classified are on the basis of the detection [3] of the fault after it has occurred. This is an important part as after the fault is detected it can be repaired. Table-III shows this classification.

TABLE III
DETECTION CLASSIFICATION FOR POWER TRANSFORMERS

Value	Detection	Criteria
1	Level F	Good Identification
2	Level E	Fair Identification
3	Level D	Good detection and rough identification
4	Level C	Fair detection
5	Level B	Rough detection
6	Level A	Complementary test

A numerical value called Priority Number (PN) is assigned to each fault which depends on the fault value from the above three tables. This number decides the action needed to be taken after the fault occurs. PN is calculated by Eq. 2

$$PN = Severity * Occurrence * Detection \quad (2)$$

The minimum number of PN for any fault is 1 and the maximum is 120. The PN is also used to forecast the probability of the fault going to occur before it does, so that required action can be done to prevent it before it happens

III. FAILURES, CAUSES & IMPACT

Faults may occur in different parts and components of the transformer due to mechanical, electrical or thermal stress caused due to different conditions. Some of the most commonly occurring failures of the transformer and their causes are listed below.

1. Winding failure

Windings are an important part of a transformer. In distribution side transformers there are commonly two windings. One on the primary side and the second on the secondary side.

High voltage/low current flows in the primary side winding and through electromagnetic induction voltage is stepped down and current stepped up in the secondary side winding. These windings withstand dielectric, thermal and mechanical stress during this process. The faults that occur in the winding are due to these stresses [4]. This causes the breaking of the windings or the burn-out. The winding fault PN number is usually between 6 to 30.

A. Dielectric faults occur in the winding due to turn-to-turn insulation breakdown. These are the insulation between the turns of the winding. Insulation breakdown commonly occur due to high current and voltage which are high above the rated values. The breakdown of the insulation results in the flashover of the winding turns and cause short circuit. Two reasons for the high rating are

i. Lightning impulse attack with no lightning arresters
ii. Fault voltages

B. The windings are usually of copper. Due to the copper line resistance thermal losses occur. These thermal losses make hotspots in the winding due to bad or lack of maintenance. This over time causes wear and tear and the decrease of the physical strength up to the point of breaking of the winding.

C. Mechanical faults are the distortion, loosening or displacement of the windings. This results in the decrease of the performance of the transformer and the tearing of the turn-to-turn ratio. The main reasons that cause this fault are the improper repair, bad maintenance, corrosion, manufacturing deficiencies, vibration and mechanical movement within the transformer.

2. Bushing Failure

Bushes are insulating devices that insulate a high voltage electrical conductor to pass through an earth conductor. In transformers it provides a current path through the tank wall. Inside the transformer paper insulators are used which are surrounded by oil that provides further insulation. Bushing failure usually occurs over time [5]. Bushes failure PN number is between 24 to 48. Some of the main reasons for bushing failure are discussed below.

A. Loosening of conductors is caused by transformer vibrations which results in overheating. This heat damage the insulating paper and the oil used.

B. Sudden high fault voltages causes' partial discharge (breakdown of solid/liquid electrical insulators) which damage the bushes and causes its degeneration and complete breakdown within hours.

C. Seal breaking of bushes happen due to ingress of water, aging or excessive dielectric losses. Due to this fault core failure of the transformer occurs.

D. Not replacing of old oil over long time or its deficiency due to leakage causes internal over-flashing.

3. Tap Changer Failure

The tap changer function in the transformer is to regulate the voltage level. This is done by either adding or removing turns from the secondary transformer winding. It is the most complex part of the transformer and also an important one. Even the smallest fault results in the wrong power output [6]. The PN number is usually between 28 to 52. Some fault and causes are

A. In Run-Through fault the tap changer takes time and after a delay changes the turn ratio. The main reason for it is the relay responsible for the tap change has residue flux because of polluted oil, therefore taking time to change. The other reason for run-through fault is the spring becoming fragile over time.

B. Lack of maintenance causes the shaft connection between the tap and the motor driver of the tap changer to be not synchronous. Because of this the tap changer is not in the position where it needs to be.

C. Old capacitors or burned-out capacitor in the motor causes the tap changer to fail to control its direction movement.

D. Regular use of the tap changer causes the spring in it to slowly become fragile over time and then finally break. Because of this the tap changer is not able to change the turn ratio of the winding.

E. Breakdown of the motor in the tap changer because of over voltage or miss-use also causes the tap changer to fail to change the turn ratio of the winding.

4. Core failure

The transformers have laminated steel cores in the middle surrounded by the transformer windings. The function of the core is to concentrate the magnetic flux. Fault in the core directly affect the transformer windings, causing faults in them. The cores of the transformers are laminated to reduce eddy-current. The lamination of the core can become defected by poor maintenance, old oil or corrosion. The breakdown of the smallest part of the lamination results in increase of thermal heat due to eddy-current [7]. The effects of this over heating are

A. The over-heating reaches the core surface which is in direct contact with the windings. As a result of this the windings are damaged by the heat.

B. This heat also damages the oil in the transformers resulting in the release of a gas from the oil that damages other parts of the transformer.

The PN number of the core failure is often 6.

5. Tank Failures

The function of the tank in the transformer is to be a container for the oil used in it. The oil in the tank is used for insulation and cooling. The tank can also be used as a support for other equipments of the transformer [8]. The PN number for the failure is 18.

The fault in the tank occurs due to environmental stress, corrosion, high humidity and sun radiation resulting in a leakage or cracks in the tank walls [6]. From these leakages and cracks oil spill from the tank causing the reduction of oil.

A. The reduction in oil level results in the reduction of insulation in the transformer and affecting the windings.

B. The oil is also used for cooling purposes so the reduction of oil causes over-heating with damages different parts of the transformer.

6. Protection system Failure

The main function of the protection system is to protect the transformer from faults by first detecting the fault and then resolving it as fast as possible. If it cannot fix the fault, it isolates it so that it may not damage the transformer.

Protection systems include the Buchholz protection, pressure relief valve circuitry, surge protection and Sudden Pressure Relays.

This is the most occurring failure with a PN between 22 to 64.

A. Buchholz protection is a protective device that is sensitive to dielectric faults in the transformer [9]. Overheating of the relay occurs because of accumulation of gasses over time, which reduces its sensitivity to dielectric faults. Low level oil due to leakage causes the Buchholz protection to come into action even if there is not a fault which is not needed and waste of energy.

B. Pressure relief valve circuitry protects the transformer from exploding due to gas pressure. The gas pressure is produced due to overheating of oil [9]. Pressure relief valve circuitry slowly reduces the pressure of the gasses. Fault in this circuitry mainly occurs due to the spring init becoming fragile over time resulting in the circuitry not being able to reduce pressure quickly. This circuitry also fails when gas pressure increases quickly as this is only able to release pressure slowly.

C. Surge protector protects the transformer from over voltage by allowing specific magnitude of voltage to go to transformer and for the rest alternate route is found. Failure in surge protection causes high voltage to pass to the windings which becomes damaged because of it [10]. Moisture, heat and corrosion are the main reasons of the failure of surge protection as it causes overheating and short circuit in it.

D. Sudden Pressure Relays protects the transformers from blowing up from sudden exponential increase of gas pressure [9]. If it fails to release the sudden pressure the transformer blows up. Relay fails due to humidity and moisture affecting its internal circuitry.

7. Cooling system failure

Cooling system reduces the heat produced in transformers due to copper and iron losses. The cooling system contains cooling fans, oil pumps and water-cooled heat exchangers [11]. The failure in the cooling system causes the heat to build up in the transformer which effect different parts of the transformer and also causes more gas pressure to be built inside which may cause the transformer to blow. The PN is between 26 to 48. Some of the main reasons for failure are discussed below.

A. One of the biggest reasons of cooling system failure is leak in the oil/water pipes. This causes the reduction in the fluids which results in low heat exchange which is not good for the transformer. Leakage happens because of environmental stress, corrosion, high humidity and sun radiation.

B. Some failure occurs due to fault in the cooling fans which rush-in cool air into the tanks for cooling purpose. The fans create faults because of poor maintenance, over use or motor wear-out.

Cooling system can perform wrong due to bad thermostats which measure the heat in the transformer. Faulty thermostats show wrong temperature causing the cooling system to operate accordingly and not in the way needed

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IV. Failure Percentage

The transformer faces many different failures. All these failures have different PN numbers which depend on their severity, occurrence and detection. Table-IV shows the different types of failures with their PN.

TABLE IV
FAILURE PRIORITY NUMBER (PN)

Failure Type	PN
Winding	6-30
Bushing	24-48
Tap Changer	28-52
core	6
Tank	18
Protection System	22-64
Cooling System	26-48

The most occurring faults and failures happen in the protection system. It is followed by tap changer and then by bushing. Their PN is high respectively.

The least occurring failure is in the core and then followed by the tank. It can be seen that these also have low PN.

Fig-1 shows the faults and the percent that they occur in [12]

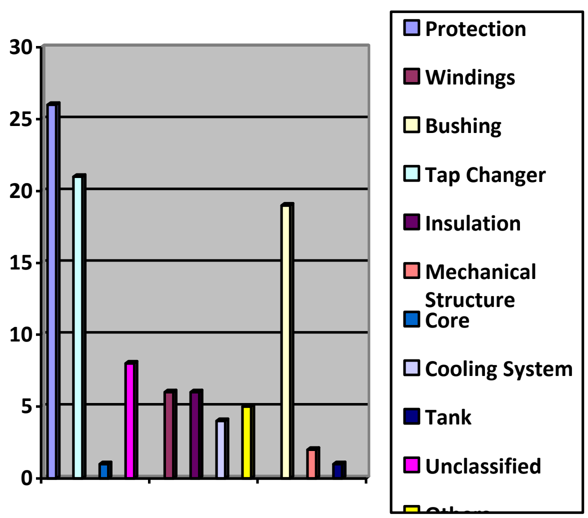

Fig. 1 Failure in transformers

V. Conclusion

A single distribution transformer has many different parts which work in correspondence with each other. All these different parts have different faults which cause different failures. Some are more severe than other, some occur more frequently while some are hard to detect.

One thing that is clear is that a single fault not only has affect on that specific component but on many others in the transformer therefore a bigger failure occurs in the transformer from a small fault. Even the smallest fault must not be ignored.

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