Fault Analysis of a Large Auto Transformer in a Power Transmission System

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ABSTRACT
The paper gives a brief overview of electric power system and role of power transformers. The faults in transformers and their protections will be briefly discussed. The damages caused by the occurrence of fault due to some abnormal conditions resulting in consequential severe damages. The root cause of the damage is normally established by conducting various tests at low voltage. A special case will be discussed when due to extensive damages to the transformer; it is not possible to conduct low voltage tests. The paper will explain as to how the cause of damage is established by very minute study of the type and extent of damages.

Keywords: Faults in power transformer, bursting of transformer, analysis of transformer failure

I INTRODUCTION

An electric power system is a network of electrical components to generate electric power in the power plants, transmit the power to the load centres using transmission lines called grid, and distribute to the consumers for domestic, irrigation, industry use etc. as shown in Fig. No. 1. Globally, the power systems have mostly adopted three-phase AC power for generation, transmission and distribution. The use of high voltage direct current (HVDC) power transmission is preferred for long distance bulk power transmission as it is economical.

The power plant generates the power which is stepped-up through the transformer for transmission at higher voltage to minimize the transmission losses. The power is transmitted to the various substations. The voltage is stepped-down using the distribution transformer for supply to the consumers at a voltage as per their need.

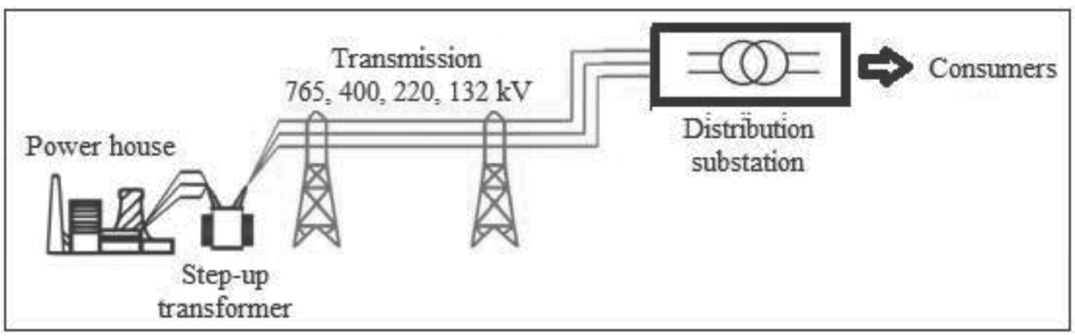

Fig. 1: Power system schematic

The generation is by the conventional sources of energy such as thermal, hydro, and nuclear. However, during last decade, renewable sources of energy are growing rapidly. The voltage at the power house is stepped-up for high voltage AC transmission to minimize the losses. The voltage is stepped-down for supplying electric power to the consumers.

Transformers are the highest voltage static electrical machine used in the power system. The maximum transmission voltage in operation in India is 765 kV. The next stage is for 1200 kV AC transmission for which the transformers of Power Grid Corporation of India Limited have been successfully tested at CPRI, Bina, Madhya Pradesh. The transformers used at power stations are conventional type whereas auto-transformers are preferred as an economical option to supply power to the feeders.

An autotransformer has magnetic core as usual but has only one winding which is used as primary as well as secondary winding. Thus, two windings are linked magnetically and electrically. The winding is tapped at number of points along its length so that an appropriate tap is selected to apply desired voltage across load as shown in Fig. No. 3. The main advantage of autotransformer is that for the same VA rating, it is cheaper and overall dimensions and weight are also less.

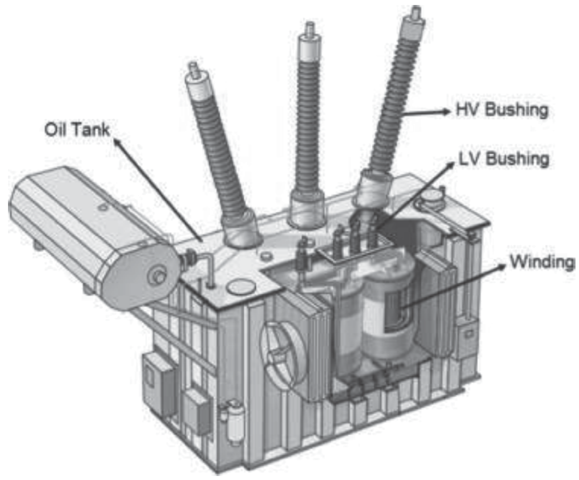

Fig. 2: Main parts of a power transformer [1]

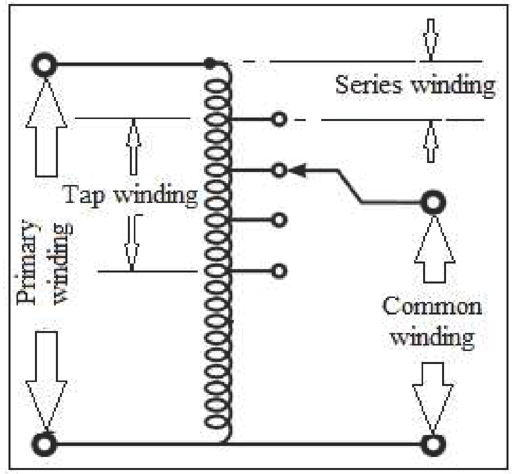

Fig. 3: Schematic of auto-transformer winding

The author discusses the power system and role of transformer along with the faults that occur along the protection. A case of 100 MVA, 400/220/33 kV, 3-phase, 50 Hz auto-transformer is presented which suffered extensive damages due to the fault resulting in the bursting of transformer tank and catching of fire. Analysis of the damages had to be carried out to establish the cause of fault as it was not possible to carry out low voltage test to determine the cause of occurrence of fault.

II FAULTS AND PROTECTION SYSTEM IN POWER TRANSFORMERS

A fault i.e. abnormal condition in a transformer 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.

The transformer faults are internal and external type. The internal faults are the earth faults, core faults, inter-turn faults, phase-to-phase faults, and tank faults. Similarly there are some external faults. In order to prevent the occurrence of faults and to minimize the damage in case of a fault, transformers are equipped with protective relays and monitors. The transformer must be isolated at the earliest on occurrence of fault.

(a) Internal Faults

- **(i) Earth faults: A** fault on a transformer winding results in flow of currents depending on the source, neutral grounding impedance, leakage reactance of the transformer, and the position of the fault in the windings. The winding connections also influence the magnitude of fault current.
- **(ii) Core faults:** The core faults due to insulation breakdown can permit sufficient eddy-current to flow to cause overheating, which may reach a magnitude sufficient to damage the winding.
- **(iii) Inter-turn faults:** The inter-turn faults occur due to winding flashovers caused by line surges. A short circuit of a few turns of the winding will give rise to high currents in the short-circuited loops, but the terminal currents will be low.
- **(iv) Phase-to-phase faults:** The phase-to-phase faults rarely occur but they result in substantial currents of magnitudes similar to those of earth faults.
- **(v) Tank faults:** The tank faults occur due to loss of oil which reduce winding insulation and increase the temperature abnormally.

(b) Protection against internal faults

Differential protection scheme provides the protection against the internal faults.

(c) External Faults

The abnormal conditions due to external factors result in stresses on the transformer. These conditions include overloading, system faults, over voltages, and over fluxing.

- **(i) Overloading:** It results in increase in temperature. Thermal relay protection is provided.
- **(ii) Over fluxing:** The over fluxing may result due to the operation at rated voltage and under frequency. The over fluxing may also be caused due to operation at over voltage and rated frequency. It results in increased iron loss and magnetizing current.

(d) Protection against external faults

- **(i) Buchholz protection:** The gases are released due to burning of oil and insulation and they are collected in the Buchholz relay. These gases are analyzed to get indication of the possible fault.
- **(ii) Pressure relieve valve:** When the pressure due to gases release due to burning of insulation exceeds preset limits.
- **(iii) Lightning protection:** The lightning stroke will result in sudden and excessive rise in voltage. The lightning arrester is provided for protection.

III DAMAGES TO TRANSFORMER

The 400 kV autotransformer was in operation satisfactorily for about 5 years. The fault occurred during rainy season which resulted in bursting of transformer tank resulting in huge fire and extensive damage in spite of the provision and automatic actuation of the firefighting equipment. The inspection and investigation by a transformer expert was done to establish the cause of fault.

(a) Occurrence of fault and protective system

During investigation it was observed that differential protection system operated at the occurrence of fault and differential protection relay was actuated. However, other protections such as Buchholz relay, pressure relive valve, winding temperature relay and oil temperature relay did not operate.

(b) Damages in transformer

During inspection of damaged transformer, following major damages were observed:

(i) HV bushing

- W-phase bushing along with turret dislodged from the transformer tank and was thrown 6 to 7 m away on ground.
- V-phase bushing also got burst and current transformer (CT) installed inside the turret was damaged and flied away.
- U-phase bushing along with turret remained in intact.

The air end and oil end portions of HV bushings of V and W phase was completely shattered. Its core was found to be burnt due to fire. The bushings used were oil impregnated type and its oil was non-communicating type i.e. totally isolated from the oil filled in transformer tank.

Fig. 4: Damaged bushings

(ii) Transformer tank & outer fittings

Transformer tank was found in intact, however, bulging was noticed at the rim joint at the end of V-Phase.

The accessories such as marshalling box, cables, piping along with fire fighting system got distorted and damaged.

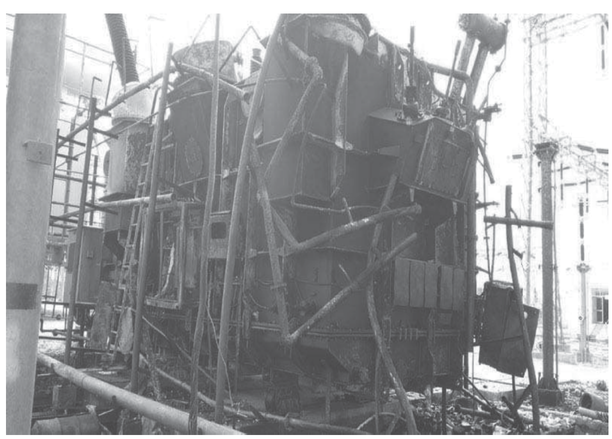

Fig. 5: Damaged transformer

(iii) HV bushing / LV bushing / terminal gear (internal)

- Transformer winding profile appeared intact and no distortion/ bulging were visible. However, the windings were found burnt on the outer periphery due to fire.
- Terminal gear of transformer windings found charred / burnt inside tank.
- The corona shield of HV bushing was dislodged from its position and damaged. It was found fallen in the tank.
- The Current Transformers of W & U Phases 420 kV installed in the turrets were found completely burnt and their turrets were found charred from inside.

(iv) Core & Winding

General Profile of core and winding inside the tank was found in shape but burning was noted on the surfaces of windings and associated terminals.

IV DAMAGE ANALYSIS TO ESTABLISH THE CAUSE

In normal course winding ratio, resistance, magnetizing current/magnetic balance and tan delta tests are conducted to establish the cause of fault. However, due to the extensive damages to HV leads and terminal gear due to the fire inside the tank, it was not possible to conduct low voltage tests the transformer.

The reason of failure is most likely due to the condenser failure of 2W (420 KV) bushing resulting in its bursting. Subsequent to the failure, there would have been repeated flash over between bushing corona shield and tank wall till actuation of protection.

The repeated flash over between 420 kV bushing stress shield and tank built-up very high pressure leading to the bursting of the bushing, arcing hot oil with exposure of air combined together had resulted in huge fire inside the transformer. Thus, the transformer got totally damaged.

Initiation of failure of 2W (HV) bushing and flash over between stem shields to tank caused failure of companion bushing 2V (HV). This spread the fire extensively, mainly inside the transformer.

V CONCLUSION

The paper presented an overview of electrical power system and power transformers, both conventional and auto transformers. The faults in transformers and their protection system have been briefly discussed. The damages due to faults caused by abnormal conditions result in damages. The root causes of the damage are established by conducting tests at low voltage. A special case was presented in which it was not possible to conduct low voltage tests due to extensive damages in the auto-transformer of a power transmission system. In such a case a precise investigation and study of the damages by highly experienced experts were carried out to establish the cause of damage to the transformer.

The failure of transformer and consequential damages were so severe that complete transformer i.e. winding/core and tank along with fittings were totally damaged. Hence, the transformer was beyond repair and there was no other option but to scrap it.

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