WWW.IJRPR.COM

International Journal of Research Publication and Reviews

Journal Homepage: www.ijrpr.com ISSN 2582-7421

Buchholz Relay Protection of Power Transformer

Bagul Roshan Pandurang[1] and Dhanshri Shantaram Dhanwate[2]

[1,2] Department of Electrical Engineering, NIT's Late Annasaheb Patil Polytechnic, Nashik, Maharashtra, India
roshanbagul251@gmail.com, dhanshridhanwate96@gmail.com

ABSTRACT—

Power transformers are among the costliest and most important elements of a power system, and an internal fault can cause long outages, fire and heavy financial loss. Electrical relays such as differential and overcurrent relays respond to current, but many faults inside an oil-filled transformer first appear as gas generation and oil movement. The Buchholz relay is a gas-operated mechanical relay fitted in the pipe between the main tank and the conservator to detect exactly these effects. This paper presents the need for transformer protection, the construction of the relay, its two-stage working principle (alarm on slow gas accumulation and trip on oil surge), installation requirements, gas analysis for fault diagnosis, testing and maintenance, and a comparison with other protective devices. A mathematical description of gas accumulation and oil-surge detection, an operating-logic flowchart, an alarm and trip circuit, and a test plan for a polytechnic laboratory are also given. The paper concludes that the Buchholz relay, used together with differential protection and dissolved gas analysis, remains an essential, economical and reliable protection for oil-immersed transformers.

***Index Terms*—Buchholz relay, power transformer, gas-operated relay, transformer protection, incipient fault, conservator, dissolved gas analysis, oil surge.**

I. INTRODUCTION

The power transformer is the heart of a transmission and distribution network. It raises the voltage for economical transmission and lowers it again for safe use by consumers. Because of its high cost, long manufacturing time and importance for continuity of supply, the protection of the transformer receives special attention [1], [7], [9]. A large transformer may cost many crores of rupees, and its failure can interrupt supply to thousands of consumers for weeks.

A transformer has no moving parts and therefore has a lower fault rate than a rotating machine. However, when a fault does occur inside the tank, the arc decomposes the insulating oil and the solid insulation, and gases are produced. If the fault is not cleared quickly, the gas pressure can rupture the tank and cause fire. Many such faults begin as small local overheating or weak insulation and grow slowly over days or weeks. They are called *incipient faults*, and they do not always change the terminal currents enough to operate an electrical relay.

The Buchholz relay was invented by Max Buchholz in Germany in the early 1920s and is still fitted on almost every oil-immersed transformer that has a conservator [7], [10]. It does not measure current or voltage. It detects the *gas* and the *oil movement* produced by a fault, and needs no external power for sensing. In India the gas-operated relay is covered by IS 3637 [5], and it is normally provided on transformers rated above about 500 kVA.

A. Problem Statement

To study a protective device that (i) detects slow, incipient faults inside an oil-immersed transformer before they become severe, (ii) detects severe internal faults and trips the circuit breakers quickly on both sides, and (iii) gives the maintenance engineer a first indication of the type of fault from the gas collected, while remaining simple, rugged and economical.

B. Objectives

- To study the types of internal faults in oil-immersed power transformers and the gases they produce.
- To explain the construction and two-stage working principle of the Buchholz relay.
- To describe installation, gas analysis, testing and maintenance practice.
- To compare the Buchholz relay with other transformer protections and to plan a laboratory test on a model.

C. Scope of the Paper

The paper is a technical study meant as a learning resource. The relay settings and gas volumes given in this paper are typical values only; the actual values must always be taken from the nameplate and instruction manual of the relay and transformer. The test plan in Section V describes a safe demonstration on a transparent model and must not be carried out on a live transformer.

II. BACKGROUND AND RELATED WORK

A. Faults in Power Transformers

Transformer faults are broadly divided into *external* faults (through-faults, overloads and overvoltages) and *internal* faults, which occur inside the tank. Internal faults are further divided into incipient and active faults [1]. Incipient faults include loose or poor connections that overheat, partial discharge in the insulation, failure of core lamination insulation, failure of the cooling system and loss of oil by leakage. Active faults involve heavy current: a winding-to-earth fault, a phase-to-phase fault, an inter-turn short circuit, and tap-changer or bushing failures.

B. Conventional Transformer Protections

A complete scheme uses several devices. *Differential protection* compares the currents entering and leaving the transformer and trips for winding and terminal faults. *Overcurrent and earth-fault relays* give back-up for external faults. *Temperature indicators* warn of overheating, and a *pressure relief device* vents the tank when the pressure becomes dangerous [2], [7]. These devices respond to electrical or thermal quantities, or to a high pressure that has already built up. A fault of low energy, such as a few shorted turns or a hot joint, may produce very little change in current and can remain undetected by them for a long time.

C. Gas Generation in Transformer Oil

Mineral oil is a mixture of hydrocarbons. Under local heat or an electric arc the molecules break and form gases that stay dissolved at first and then escape as bubbles. The gases include hydrogen, methane, ethane, ethylene and acetylene, and carbon monoxide and carbon dioxide when paper insulation is involved [3], [4]. The higher the temperature at the fault, the more unsaturated the gases become: ethylene is typical of a hot spot, and acetylene is a mark of arcing. This chemistry is the reason why gas detection gives an early and reliable indication of an internal fault.

D. Standards and Practice

Gas-operated relays are specified by IS 3637 in India [5], and the general requirements of oil-immersed transformers, including the conservator and its fittings, are given in IEC 60076-1 [6]. IEEE C37.91 gives a guide for protecting power transformers and lists the gas relay among the devices used for internal faults [2]. Interpretation of the gases is guided by IEEE C57.104 [4].

E. Comparison of Protective Devices

TABLE I

COMPARISON OF TRANSFORMER PROTECTIONS

Device	Detects	Main limitation
Buchholz relay	Gas, oil surge, low oil (inside tank)	Only conservator type; inside tank only
Differential relay	Winding and terminal faults	Not sensitive to all incipient faults
Overcurrent / earth fault	External faults, back-up	Slow, low sensitivity inside
Temperature indicator	Overheating, overload	Slow thermal response
Pressure relief device	High tank pressure	Acts after pressure builds

F. Types of Gas-Operated Relays

Three arrangements are common. The *single-float* relay has only one float and gives an alarm for gas; it is used on small transformers. The *double-float* relay has two floats, one for the alarm and one for the trip. The *float-and-flap* relay, which is the most widely used form, has an upper float for the alarm and a flap in the oil path for the trip, and a lower float is added in some designs to trip on a very low oil level. All of them work on the same principles of gas collection and oil surge.

III. CONSTRUCTION OF THE BUCHHOLZ RELAY

Fig. 1 shows where the relay is placed. The conservator is a small tank mounted above the main tank that allows the oil to expand and contract with temperature. It is joined to the main tank by a pipe, and the Buchholz relay is fitted in this pipe, as close to the tank as possible. Any gas produced in the tank must rise through this pipe, and any sudden oil flow toward the conservator must pass through the relay.

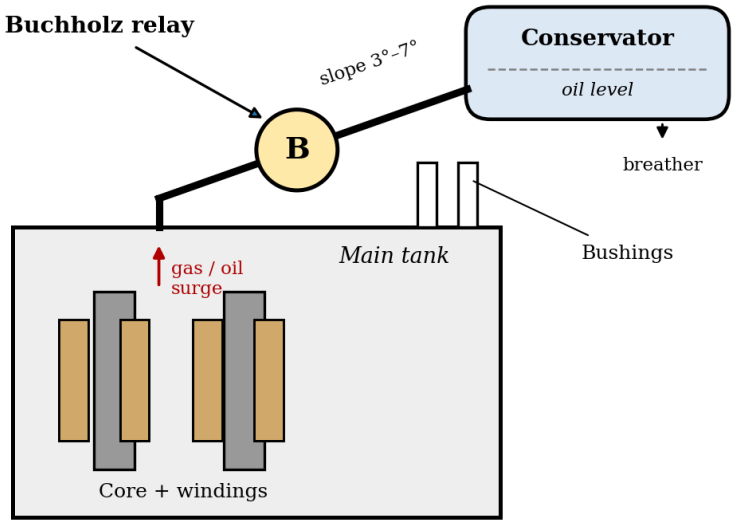


Fig. 1. Position of the Buchholz relay between the main tank and the conservator.

A. Housing and Oil Space

The relay is a cast-metal housing with flanged ends that bolts into the pipe. In service it is completely filled with transformer oil. A glass window with a graduated scale in cm^3 allows the volume of gas to be read, and a petcock at the top allows the gas to be drawn off for testing.

B. Float and Flap Elements

Fig. 2 shows the main elements. The *upper float* F1 is hinged near the top of the housing and carries a switch, usually a sealed reed or mercury contact S1, which is connected to the alarm circuit. The *lower element* is either a second float F2 or a *flap* (baffle plate) placed in the direct path of the oil flow, and it carries the trip switch S2. Older relays use mercury switches in glass tubes; modern relays prefer sealed magnetic reed switches, which are less sensitive to vibration and do not contain mercury.

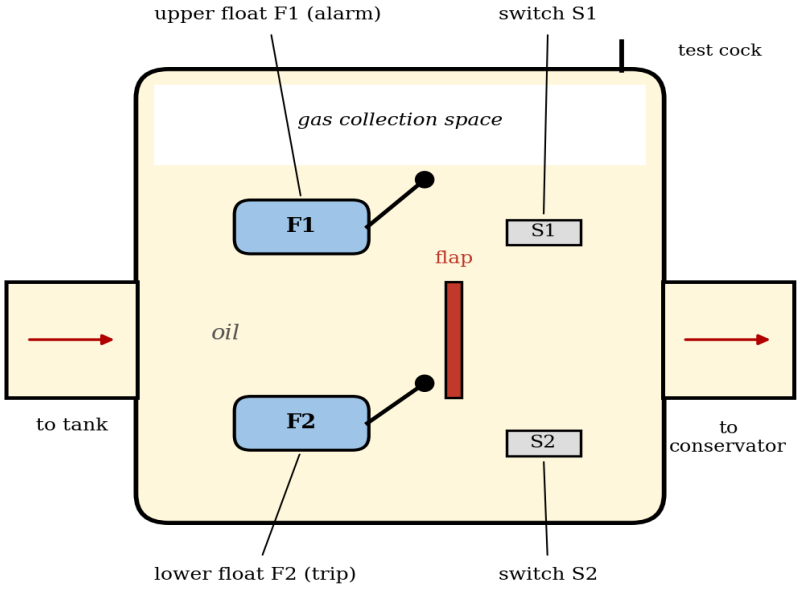


Fig. 2. Schematic section of a double-float Buchholz relay (alarm element F1, trip element F2 and flap).

C. Auxiliary Parts

The relay also has a terminal box, with weatherproof cable glands, for the alarm and trip wiring, and a test push-button or test cock to check the mechanism. Table II lists the parts and their functions.

TABLE II

MAIN PARTS OF THE BUCHHOLZ RELAY

Part	Function
Housing	Oil-filled chamber in the pipe line
Upper float F1	Falls as gas collects; closes alarm contact
Lower float F2 / flap	Responds to oil surge or very low oil; closes trip contact
Reed / mercury switch	Sealed contact for alarm and trip circuits
Inspection window	Scale in cm^3 to read gas volume
Gas release cock	Draws off gas sample; bleeds air
Test button / cock	Checks float and trip mechanism
Terminal box	Weatherproof wiring connections

D. Relay Size and Selection

The manufacturer selects the size of the relay and of the connecting pipe according to the rating and cooling type of the transformer, because the oil flow during a fault depends on the size of the transformer and on the pipe diameter, as shown by (2) in the next section. A relay for a large transformer is therefore set to operate at a higher oil velocity than one for a small transformer. The relay is also chosen with the correct flange size, contact rating and ambient temperature class, and its terminal box should have a degree of protection suitable for outdoor use.

IV. WORKING PRINCIPLE AND METHODOLOGY

A. Normal Condition

In the healthy state the housing is full of oil, both floats are buoyant and rest in their upper position, and the flap hangs in a free position. Both contacts are open. Slow movements of oil caused by load or temperature changes pass through the relay at low velocity and do not disturb the elements.

B. Alarm Stage: Slow Gas Accumulation

During an incipient fault the gases rise through the oil and are trapped in the upper part of the housing, because the relay is wider than the pipe and the gas cannot pass through it quickly. The gas displaces the oil, and the oil level inside the relay falls. The gas volume at time t is the integral of the gas flow rate q_g produced by the fault:

$$V_g(t) = \int q_g \, dt \qquad (1)$$

When V_g reaches the set value V_{set}, typically in the range of about 100 to 300 cm^3 depending on the make, the upper float F1 tilts far enough to close the switch S1 and the *alarm circuit* operates [6]. The operator is warned and can examine the transformer without any loss of supply. The same alarm occurs when the oil level falls because of a leak, since the float follows the oil level.

C. Trip Stage: Oil Surge

A severe fault such as a winding-to-earth short circuit produces a very large amount of gas within a few milliseconds. The rapidly expanding gas drives a surge of oil along the pipe toward the conservator. For a flow rate Q in a pipe of internal diameter d, the mean oil velocity is

$$v = Q/A = 4Q/(\pi d^2) \qquad (2)$$

The surge strikes the flap (or deflects F2) and, when the velocity exceeds the setting v_{set}, closes the trip switch S2:

$$v \geq v_{set} \Rightarrow \text{S2 closes} \qquad (3)$$

The flap setting is adjusted to the pipe size and cooling type. Typical settings are of the order of 65 to 150 cm/s, chosen so that normal oil movement or the starting of an oil pump does not cause a false trip [6]. The trip circuit energises the trip coils of the circuit breakers on both the high-voltage and low-

voltage sides. If the oil level falls so low that the lower float drops, the trip circuit also operates, because a partly exposed winding must not remain energised.

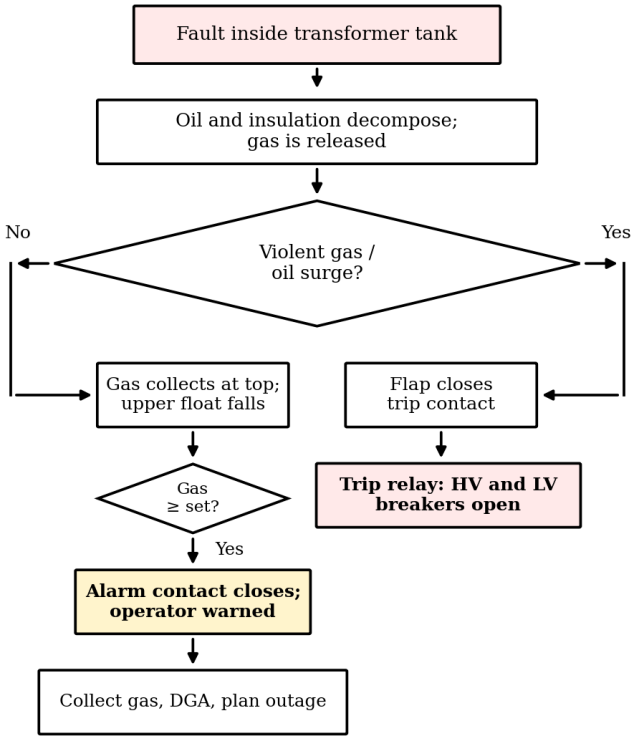


Fig. 3. Flowchart of the operation of the Buchholz relay for an internal fault.

D. Operating Logic

The decision made by the relay can be written as simple logic, shown below with the same symbols as (1)–(3). The trip branch has priority over the alarm branch, and the trip relay is hand-reset so that the transformer cannot be re-energised until the cause is found.

on each event:

if S2 closed (v >= v_set or F2 down):

energise trip relay (hand reset)

open CB_HV and CB_LV; lockout

else if S1 closed (Vg >= V_set or low oil):

sound alarm; note gas volume

sample gas; send for DGA

else: normal, no action

E. Operating Stages

Table III summarizes the two stages. The alarm stage gives an early warning without interruption of supply, while the trip stage isolates the transformer at once.

TABLE III

OPERATING STAGES OF THE RELAY

Stage	**Cause**	**Element**	**Action**
Alarm	Slow gas; falling oil level	Upper float F1	Warn operator
Trip	Heavy gas; oil surge	Flap / F2	Trip HV, LV CBs
Trip	Very low oil level	Lower float F2	Trip HV, LV CBs

F. Alarm and Trip Circuit

Fig. 4 shows the control circuit. The alarm switch S1 is connected to the DC supply and an annunciator. The trip switch S2 energises an auxiliary trip relay, which in turn operates the trip coils of the circuit breakers. A DC supply is used so that the protection remains available during an AC failure.

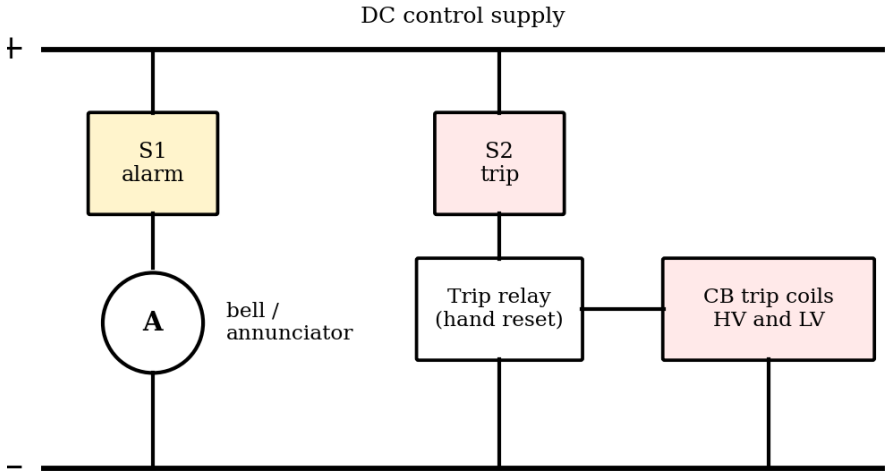


Fig. 4. Alarm and trip circuit of the Buchholz relay (simplified).

G. Co-ordination with Other Protections

In practice the trip contact of the Buchholz relay is wired in parallel with the trip contacts of the differential relay, the pressure relief device and the winding temperature trip, so that any one of them can open both circuit breakers through the same trip relay. The alarm contacts of the Buchholz relay, the oil temperature indicator and the oil level gauge are wired to a common annunciator window with separate indications, so that the operator can see which device has operated. This arrangement allows the fault to be located quickly and keeps the protection redundant.

H. Design Example: Gas Alarm and Oil Surge

A short calculation shows how (1) and (2) are used. Assume the fault produces gas at a steady rate q_g = 5 cm^3/min and the alarm is set at V_{set} = 200 cm^3. From (1) the alarm operates after 200/5 = 40 min, which gives the operator time to act. Now assume a severe fault drives an oil flow of Q = 2 L/s through a pipe of d = 50 mm. The area is $A = \pi(0.05)^2/4 = 1.96 \times 10^{-3}$ m^2, so $v = 0.002/0.00196 \approx 1.0$ m/s, or about 100 cm/s. This is above a setting of 65 cm/s and the relay trips. For the same flow in an 80 mm pipe, $v \approx 0.40$ m/s = 40 cm/s, which is below the setting. This shows why the setting must be matched to the pipe size. The values are assumed for illustration only.

V. INSTALLATION AND TEST PLAN

Correct installation has a direct effect on the reliability of the relay. Table IV lists the main requirements generally given by manufacturers and by the standard [5], [6].

TABLE IV

INSTALLATION REQUIREMENTS

Item	Requirement
Location	In the pipe between tank and conservator, near the tank
Pipe slope	Rising toward conservator, about 3° to 7°
Straight run	As specified by maker, on both sides of relay
Mounting	Level; arrow on housing points to conservator
Valves	Isolating valve kept open in service; no sharp bends
Terminal box	Weatherproof glands; rain shield outdoors
Wiring	Separate, marked alarm and trip circuits

The Buchholz relay is *not* applicable to hermetically sealed or gas-cushioned transformers, which have no conservator and use other devices such as a sudden pressure relay.

A. Installation and Commissioning Steps

1) Fit the relay with the arrow toward the conservator, after checking that the pipe slope and straight run are correct.
2) Fill the transformer under vacuum or as specified, and release all air through the cock on the relay until oil flows out.
3) Wire the alarm and trip circuits, check the insulation resistance and the continuity of the wiring.
4) Test the alarm and trip operation, then keep the transformer unloaded for some hours so that remaining air bubbles can collect and be released before loading.

B. Test Plan

Routine tests are carried out at every scheduled shutdown and after any operation of the relay. The *gas-release test* injects air through the test cock (or a pump) to lower the oil level slowly and confirms that the alarm closes at the specified gas volume. The *trip test* moves the flap with the test button, or increases the injected flow, and confirms that the trip contact closes and, during a shutdown, that both breakers open. For a classroom demonstration, a transparent model with oil, a float and a small flap can be used to show the alarm and trip action with a hand pump.

C. Evaluation Metrics

TABLE V

ROUTINE TESTS AND ACCEPTANCE

Test	Method	Acceptance
Visual check	Window, glass, gaskets	No gas, no leak
Alarm test	Air injection at cock	Closes at set volume
Trip test	Test button / flap	Trip contact closes
Circuit check	Megger, continuity	Within maker limits
Breaker trip	Isolated CB test	Both CBs trip

D. Safety

The gas collected in the relay is flammable, and the oil can be hot. The gas must be released away from flames and hot surfaces. The trip supply must be isolated or the breakers locked before testing so that no unintended trip occurs, and the work must follow the permit-to-work rules of the substation.

VI. GAS ANALYSIS AND FAULT DIAGNOSIS

A. Field Test of the Collected Gas

When the alarm operates, the colour and nature of the gas give a first, rough indication of the fault [7]. Table VI gives the traditional guide. The colour test is only a quick field aid, because the gas colour changes quickly after exposure to air, and it must never replace laboratory analysis.

TABLE VI

TRADITIONAL GAS COLOUR GUIDE

Gas observed	Probable cause
Colourless, odourless, not combustible	Air in the oil
Yellow, not combustible	Decomposition of wooden parts
Whitish-grey, sharp odour, combustible	Decomposition of paper insulation
Black or dark grey, combustible	Decomposition of oil (arcing, severe heating)

B. Dissolved Gas Analysis

Modern practice draws the gas into a gas-tight syringe and sends it, with an oil sample, for *dissolved gas analysis* (DGA) by gas chromatography [3], [4]. The pattern of the gases identifies the fault, as shown in Table VII. Acetylene in the Buchholz gas is a serious sign, since it is produced only at the very high temperatures of arcing.

TABLE VII

KEY GASES AND THEIR SIGNIFICANCE

Key gas	Typical significance
Hydrogen (H_2)	Partial discharge (corona)
Methane, ethane	Low-temperature thermal fault
Ethylene (C_2H_4)	High-temperature thermal fault
Acetylene (C_2H_2)	Arcing or very high temperature
CO, CO_2	Overheating of paper insulation

C. Action After Operation

If only the *alarm* operates, the gas volume is noted, a sample is collected, the senior engineer is informed, and DGA is arranged. If the gas is only air, it is released and the alarm is watched. If the relay *trips* the transformer, the breakers must *not* be reclosed. The transformer is isolated, gas and oil samples are taken, and electrical tests (insulation resistance, winding resistance and ratio test) are done before any decision to return it to service.

D. Illustrative Case

Consider a 10 MVA, 33/11 kV oil-immersed transformer protected by differential, overcurrent and Buchholz relays. A loose tap-changer contact causes local overheating, and gas slowly collects in the relay over several days until the alarm operates. The gas sample shows ethylene and methane with no acetylene, which points to a thermal fault. The transformer is taken out during a planned shutdown, the tap-changer is overhauled and service is restored. Because the fault was found at the alarm stage, a major failure and an unplanned outage were avoided. The case is hypothetical and is used only to show the working of the relay.

E. Limitations

- The relay detects only faults *inside* the tank; bushing and lead faults outside the oil are not sensed.
- It acts through oil movement and is slower than differential protection on severe faults.
- Air bubbles, vibration, seismic shock and nearby heavy short circuits can cause mal-operation.
- The mechanism may stick if it is not tested regularly.

F. Maintenance Schedule

A typical maintenance programme is given in Table IX. The intervals are only a guide and should follow the practice of the utility and the advice of the manufacturer.

TABLE IX

TYPICAL MAINTENANCE SCHEDULE

Interval	Activity
Routine round	Check window for gas, oil level and leaks
Scheduled outage	Alarm and trip tests; wiring and terminal check
After alarm	Record gas volume; sample gas; arrange DGA
After trip	Isolate; sample; electrical tests before reclosing
Long service	Replace gaskets; renew old mercury switches

G. Trending of Alarms

A single alarm with a small gas volume may come from air and is not alarming by itself. A series of alarms with a shorter interval each time, or a gas volume that rises faster, shows that the fault is progressing. The date, time and gas volume of each alarm should therefore be recorded and compared with the DGA results, so that the engineer can decide whether the transformer may stay in service under watch or must be taken out of service at once.

VII. STANDARDS, SAFETY AND CHALLENGES

The Buchholz relay is a supplement to, and not a substitute for, electrical protection. A differential relay and a Buchholz relay complement each other: a winding-to-earth fault near the neutral may give a very small differential current but still produces gas, while a fault in the bushing or leads outside the tank is seen by the differential relay but not by the Buchholz relay [1], [2]. The requirements of IS 3637 [5] and IEC 60076-1 [6] apply to the relay and its installation.

Mal-operation is the main practical challenge. Table VIII lists the common causes and the usual remedies.

TABLE VIII

COMMON CAUSES OF MAL-OPERATION

Cause	Remedy
Air after oil filling or topping up	Release air; keep transformer unloaded for some hours
Vibration or seismic shock	Secure relay; use reed switches
Oil pump starting	Check flap setting; limit oil velocity
Water in terminal box	Replace gasket; fit rain shield
Wrong flap setting	Reset as per manual

Transformers without a conservator, and large units that need a faster response, also use a *sudden pressure relay*, which senses a rapid rise of the pressure inside the tank. It does not replace the Buchholz relay on a conservator type transformer; the two devices respond to different effects of the same fault and are often used together.

Fire and environmental safety also matter. The trip of a Buchholz relay may indicate arcing inside an oil-filled tank, so the fire-fighting arrangements of the transformer bay should be kept ready, and oil that leaks from a damaged relay must be contained and not allowed to enter drains.

A further challenge is the maintenance of old relays that use mercury switches; these should be replaced by sealed reed types where possible.

VIII. ADVANTAGES AND APPLICATIONS

The Buchholz relay detects incipient faults early, before they become major faults, and detects faults that electrical relays may miss, such as inter-turn faults, core faults and low oil level. It is simple, rugged and inexpensive, needs no external supply for sensing, provides two-stage protection (alarm and trip), and the gas it collects helps to diagnose the fault. It is used on distribution and power transformers above about 500 kVA in substations, industries, generating stations and traction systems, and on reactors with a conservator.

Modern installations supplement the traditional relay with *online dissolved gas monitors* that measure key gases continuously and send the data to the SCADA system, and with *digital Buchholz relays* that transmit the gas volume and oil level electronically. Sealed reed switches are replacing mercury switches. Even so, the basic gas-operated principle is retained because of its reliability and low cost [8].

For diploma students the topic connects several subjects: switchgear and protection, electrical machines, insulating materials, instrumentation, and maintenance practice. Students also learn practical skills such as testing of protective devices, gas sampling procedure, safety practice and technical report writing in IEEE style.

IX. CONCLUSION AND FUTURE WORK

This paper presented the Buchholz relay as a protection of oil-immersed power transformers with a conservator. Its two-stage operation, an alarm for slow gas accumulation or low oil and a trip for severe faults with oil surge, enables early detection and quick isolation of internal faults, and reduces damage and outage time. Correct installation, careful gas analysis and regular testing are essential for dependable operation. Because the relay cannot sense faults outside the tank, it should always be used together with differential, overcurrent, temperature and pressure protections.

Future work includes building and testing a transparent laboratory model of the relay, combining Buchholz alarms with online dissolved gas monitors, using digital Buchholz relays with remote gas-volume transmission, and applying condition-based maintenance and data analysis for transformer health assessment [8].

ACKNOWLEDGMENT

The authors thank the Head of the Department, the guide and the laboratory staff of [Name of Polytechnic] for their guidance and support.

REFERENCES

[1] J. L. Blackburn and T. J. Domin, *Protective Relaying: Principles and Applications*, 4th ed. Boca Raton, FL, USA: CRC Press, 2014.

[2] *IEEE Guide for Protecting Power Transformers*, IEEE Standard C37.91.

[3] M. Duval, "A review of faults detectable by gas-in-oil analysis in transformers," *IEEE Elect. Insul. Mag.*, vol. 18, no. 3, pp. 8–17, May/Jun. 2002.

[4] *IEEE Guide for the Interpretation of Gases Generated in Mineral Oil-Immersed Transformers*, IEEE Standard C57.104.

[5] *Specification for Gas Operated Relays*, Bureau of Indian Standards, IS 3637.

[6] *Power Transformers – Part 1: General*, IEC Standard 60076-1.

[7] Badri Ram and D. N. Vishwakarma, *Power System Protection and Switchgear*, 2nd ed. New Delhi, India: McGraw-Hill, 2011.

[8] M. Wang, A. J. Vandermaar, and K. D. Srivastava, "Review of condition assessment of power transformers in service," *IEEE Elect. Insul. Mag.*, vol. 18, no. 6, pp. 12–25, Nov./Dec. 2002.

[9] J. H. Harlow, Ed., *Electric Power Transformer Engineering*, 3rd ed. Boca Raton, FL, USA: CRC Press, 2012.

[10] S. S. Rao, *Switchgear Protection and Power Systems*. New Delhi, India: Khanna Publishers.