Transformer Protection

Nature of transformer faults

- TXs, being static, totally enclosed and oil immersed develop faults only rarely but consequences large.
- Three main classes of faults.

1) Faults in Auxiliary Equipment

- Transformer Oil: low oil can expose live parts.
  - → oil level indicators.
- Gas Cushion: Deterioration of transformer oil and (paper) insulation is minimized if oxygen and moisture are excluded from the gas space. Normal operating pressure in the tank varies widely with temperature so sealing the tank is not generally undertaken.
  - Conservator tank used to house additional oil and allow for oil expansion. → silica gel on breather to remove moisture.
  - Nitrogen cylinder with regulating device (maintain pressure 0.5-0.8 atmospheres) → detect leaks or overpressure.
- Oil pumps and Forced Air Fans
  - Top oil temp gives indication of TX load. Increased oil temp might be indication of overload or cooling (fans, pump, radiator) failure.
    - Thermometer with alarm contacts
    - Oil flow indicator
- Core and Winding Insulations: incipient faults due to:
  - Poor insulation of laminations and core bolts.
  - Poor insulation, damage during installation of aging of insulation between windings, between winding and core, and conductor.
  - Badly made joints and connections
    - → none of above critical but need to be detected and repaired when convenient.
    - → gas actuated relays.

2) Winding Faults

- Electrical faults which cause immediate serious damage and are detected by unbalance current or voltage can be divided into two classes:
    - Faults between adjacent turns or parts of coils (eg phase-phase on external terminals, short circuits between turns)
    - Faults to ground or across complete windings (eg phase-earth faults on external terminals or on windings).
- Short circuit between turns can start with a point contact resulting from mechanical forces or insulation deterioration due to excessive overload, loose connection or impulse voltage.
- Faults to ground, or across large part of winding result in large fault currents and emit large amounts of gas due to decomposition of oil.
    - Not difficult to detect but must trip quickly.

3) Overloads or External Short Circuits

- Overloads can be sustained for long periods before insulation ‘aging’ occurs.
    - Monitor winding and oil temperatures → alarm and/or trip at threshold levels.
- Close in external short circuits can result in large currents through transformers and thus rapid heating.

Differential Protection of Transformers

- Any deviation from normal ratio of currents at input and output end must be due to fault in protected circuit
    - High selectivity and fast tripping time → very important and popular TX protection.
    - Differential scheme must not operate under normal load and through/external faults but must operate for sufficiently severe internal faults.
    - Vector difference of two currents fed into operating coil of relay (for external faults CT currents equal but phase opposite → no differential current)

- Star-star transformer, both windings ungrounded of unity ratio and have phase-phase fault (earth fault wont result in fault current)

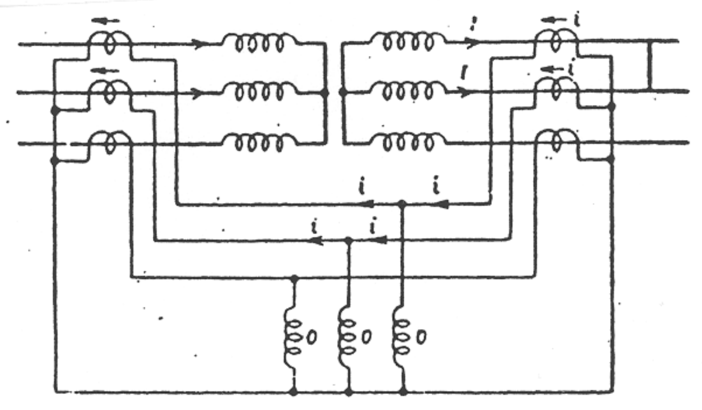


Fig. 14.46 Ungrounded star-star transformer protection, through fault

  - For external fault no current through operating coil → no operation.
  - For internal fault no operating current thus no operation
  - For star-star transformer, both windings ungrounded can use star CTs.
- Star-star transformer, HV winding ungrounded, LV grounded of unity ratio and have phase-earth fault

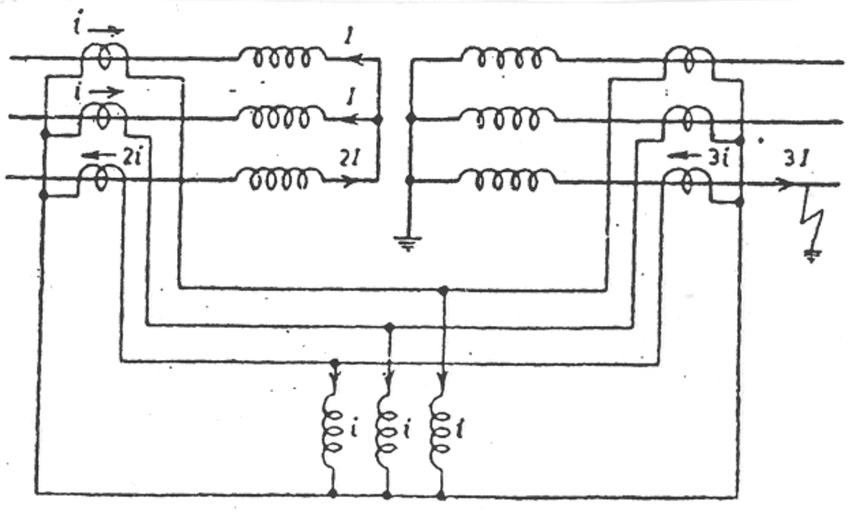


Fig. 4.47 Grounded star/star transformer protection, through fault.

  - Get 3I on LV and 2I-1I-1I on HV

- For external fault get current through operating coil → operation.
- Use rule of thumb if primary connected in star connect CT in delta.

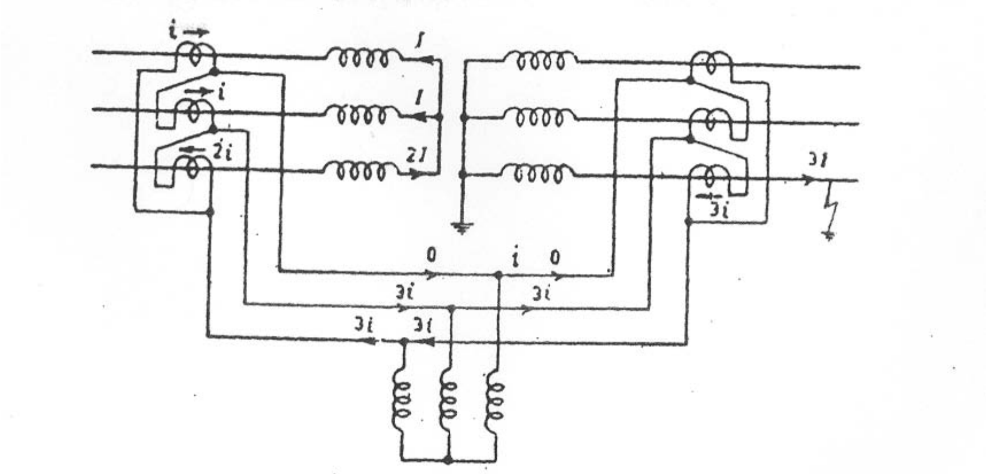


Fig. 14.48 Transformer star/star grounded C.T. delta connected protection

- For external fault no operating current → no operation.

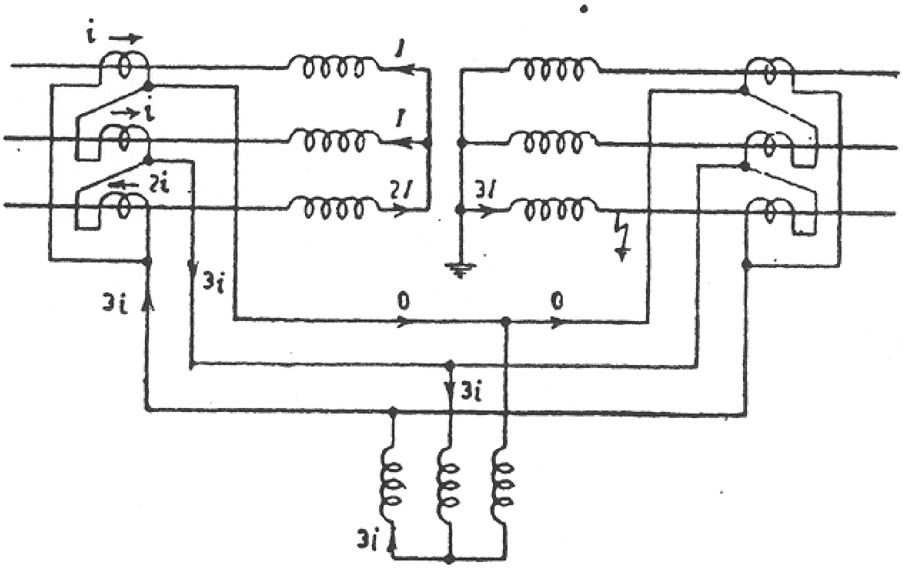


Fig. 14.49 Star/star grounded, internal fault

- For internal fault, get operating current → operation.

- Delta-star transformer, HV winding ungrounded, LV grounded of unity ratio and have phase-earth fault
  - HV and LV currents are displaced from each other by 30°
  - CTs on star side connected in delta, on delta side connected in star → nullify the phase displacement

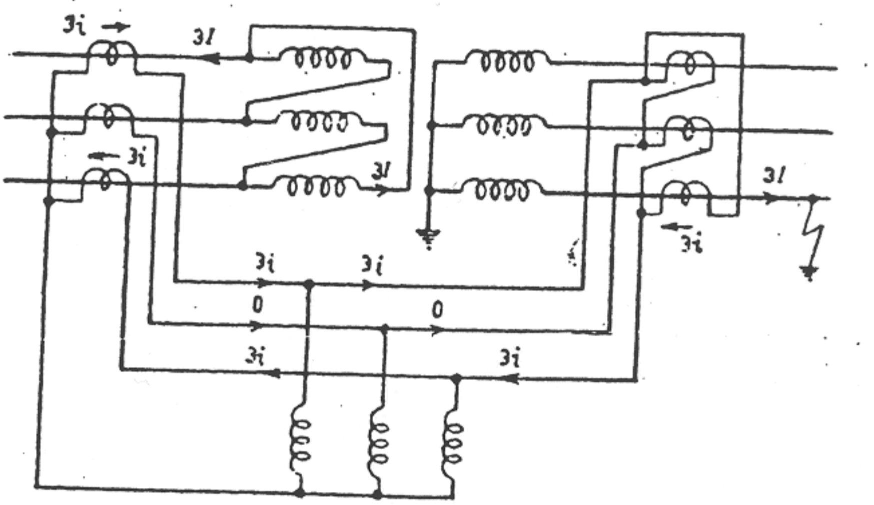


Fig. 14.50 Delta/star grounded transformer protection

  - Get 3I on LV and 3I-0-3I on HV
  - For external fault get current through operating coil → operation.
  - For internal fault, get operating current → operation.

Problems Encountered in Differential Protection of Transformers

Differential scheme on transformers suffers from the following drawbacks:

- Unmatched CT characteristics → differential current:
  - Unequal CT ratios
  - One set of CTs saturating before another set
  - Unequal CT lead burden, CT secondary resistance
- Ratio change due to tapping (tap changer used to keep LV voltage fixed irrespective of HV voltage change by changing power TX turns ratio) → differential current

- Magnetising inrush current: when TX energized magnetizing inrush current transient may be 6-10xfull load current and decay relatively slowly → differential current.
  - Size depends on point of wave (eg zero point) and remnant flux in TX
    - Prevent mal-operation by:
      - high pickup or
      - slow operating speed or
      - harmonic filtering

Percentage or Biased Differential Relays

- To avoid mal-operation for heavy through faults due to unmatched CTs and tapping ratio changes, use restraining winding energized by through current

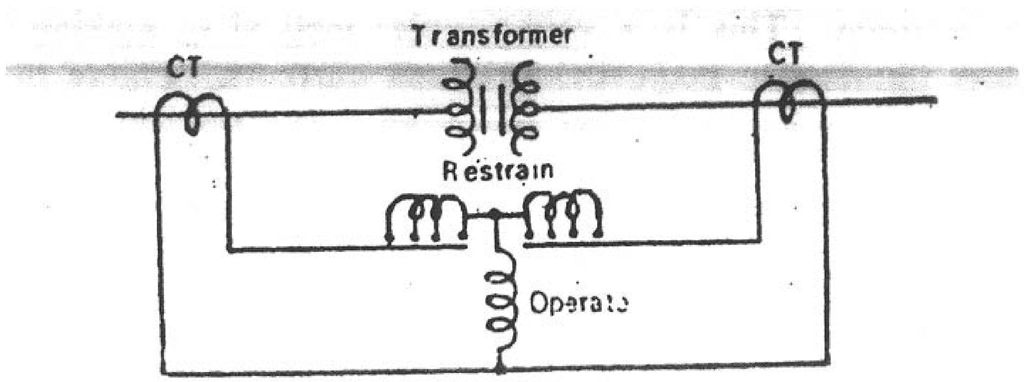
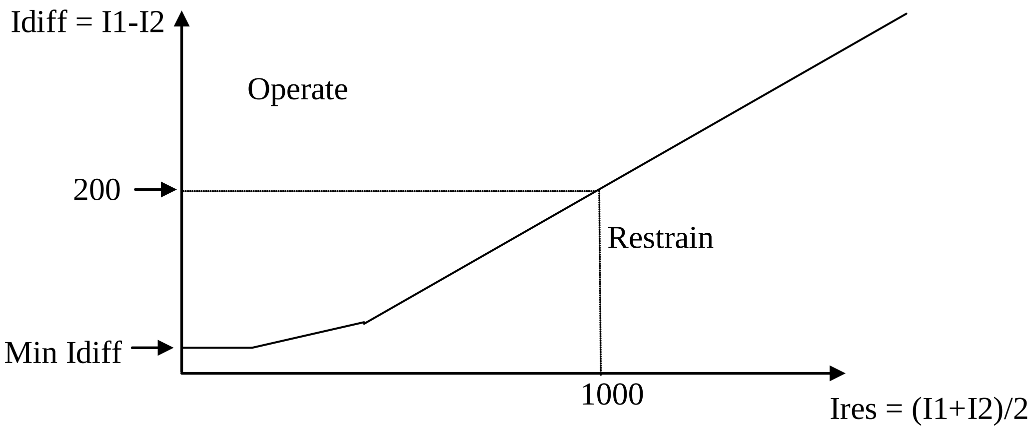


FIGURE 6.2 Biased differential protection for a transformer.

- Operating winding is biased and operates at some percentage of the through current → relay becomes more sensitive at low currents without tripping for external faults.



- Typical setting values are 50-100% for pickup setting, 10-40% for bias (depends on extent of tap changer range).
- Operation if $|(I1-I2)/T| > |(I1+I2)/2|$ where T is the bias (20% in graph above)

Method for Preventing Operation on Inrush Currents

- Magnetising inrush currents contain pronounced harmonics but internal fault currents are sinusoidal → filter harmonic current and use as restraint. Two methods:
- 1) Even Harmonic Cancellation: Example of harmonics in inrush waveform:

Component	Fund.	DC	2nd	3rd	4th	5th	6th	7th
%	100	55	63	26.8	5.1	4.1	3.5	2.5

  - this scheme can be used on star-delta transformers where the 3rd harmonic circulates in primary delta and CT secondary delta.
  - The dc and even harmonics are cancelled out of the operating circuit and used for restraint.
  - 5th and 7th harmonics are ignored.
- 2) Harmonic Restraint: operating current has only dc due to fundamental frequency, restraint has the dc proportional to bias (through) current and the harmonics.

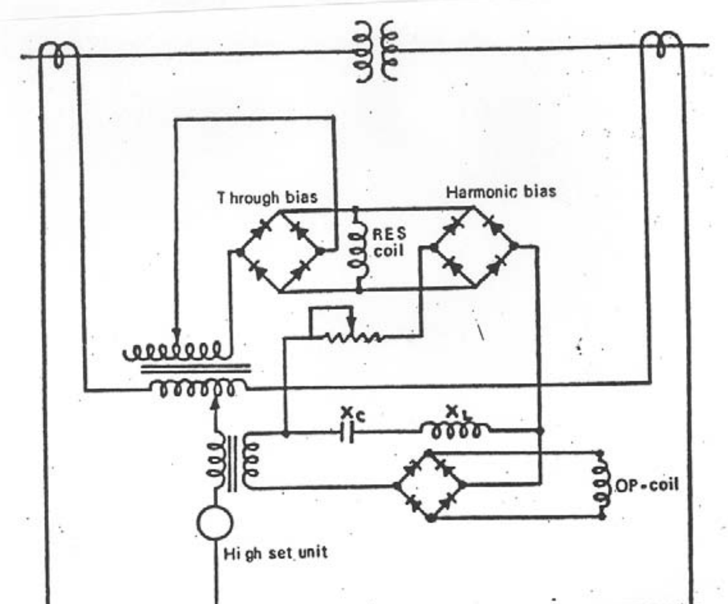


FIGURE 6.4 Basic circuit of harmonic restraint relay.

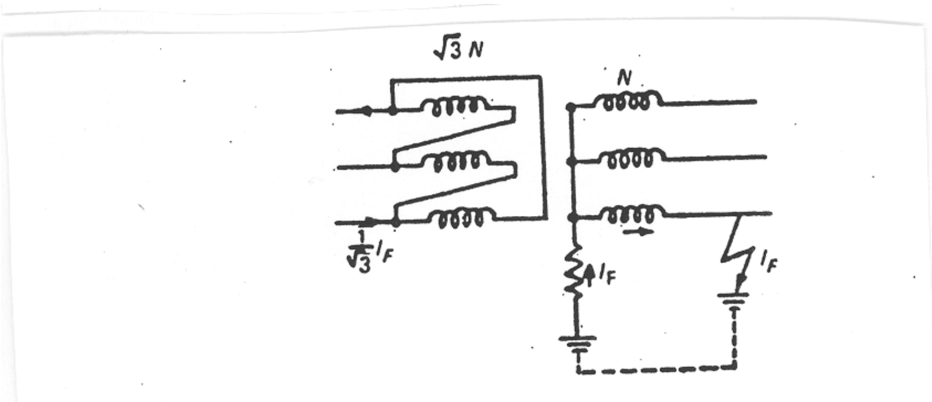
- The tuned XcXl circuit permits only 50Hz current into the operating circuit. {{{HOW – looks to me like all the harmonics go to RES coil but op coil gets 50Hz and also harmonics – adjustable resistor just encourages more or les harmonic current to go to RES?????}}
- DC and higher harmonics are diverted into restraint rectifier bridge.
- Relay is adjusted by resistor so it want operate if harmonic current exceeds 15% of fundamental.
- Harmonic restraint may result in the relay not operating on internal fault with harmonics (due to arc or CT saturation) → instantaneous overcurrent in differential circuit set above maximum in-rush (fast tripping for heavy internal faults).

Influence on Winding Connections and Earthing on Earth Fault Current

- Magnitude of earth fault current for a given fault position depends on winding connections and method of neutral earthing. For winding fault to earth to produce earth fault current require:
    - Path exists for current to flow into and out of windings (eg TX neutral is earthed or external neutral earth)
    - Ampere turns balance is maintained between windings.

Star Winding With Resistance Earthed Neutral

- Earth fault current dependant on resistor size and distance to fault from neutral end.



- Star-delta TX, 1:1 overall voltage ratio and primary to secondary turn ratio is √3:1.
- For earth fault on external secondary terminal get If/√3 on primary.
- For an earth fault x% of winding from neutral, secondary fault current is xIf/100, effective turns ratio is now √3:x/100 as 1-x of winding is shorted out → primary current will be $(If(x/100)^2)$ /√3
- LV more sensitive.

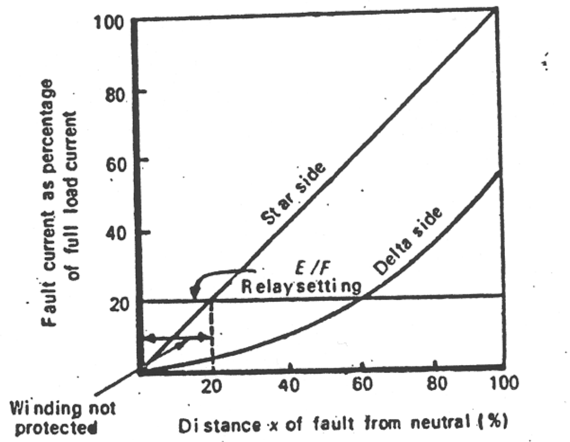
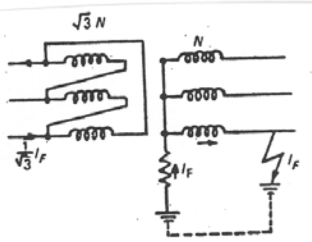


FIGURE 6.5 Transformer earth fault for resistance-earthed star winding.

Star Winding with Neutral Solidly Earthed

- Earth fault current limited solely by winding impedance.
  - Leakage reactance of faulted winding in terms of reactance per turn increases closer fault is to star point but reactance of other winding is effectively reduced owing to change in transformation ratio → fault current minimum near centre of winding.



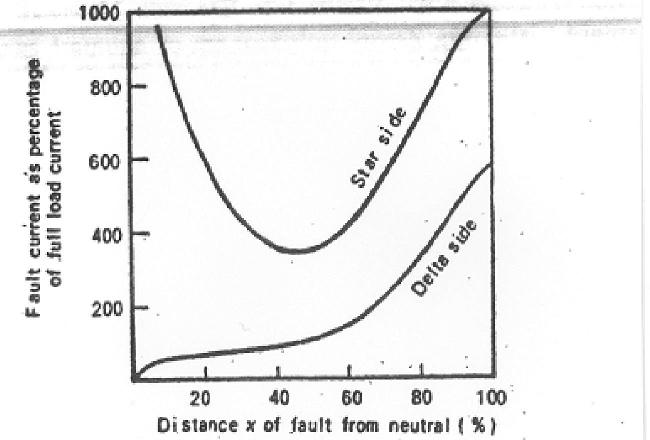
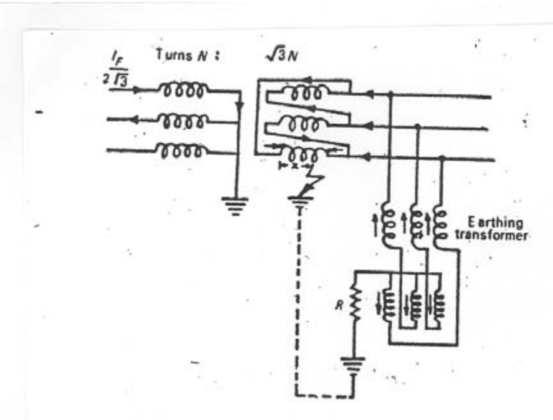


FIGURE 6.6 Transformer earth fault for solidly-earthed star winding.

Delta Winding

- Minimum voltage and occurs at mid



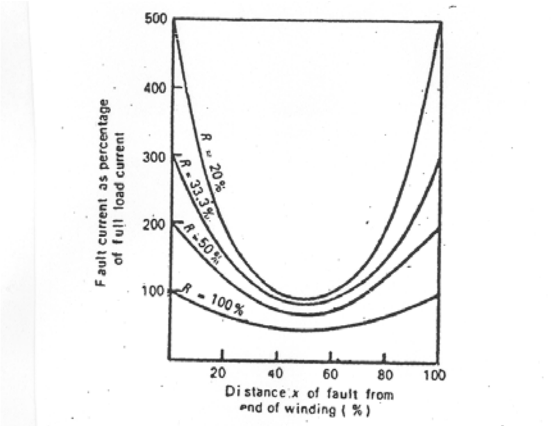


FIGURE 6.7 Transformer earth-fault for delta winding system, system resistance earthed.

Overcurrent and Earth Fault (Unrestricted)

- O/C and E/F using IDMT relays used to protect TX against external uncleared short circuits, excess overloads and backup to differential.
- Minimum fault current > O/C pickup > short term overloads
- Time settings to grade with down stream relays.

Restricted Earth Fault Protection

- Provided to detect earth fault on transformer below sensitivity of biased differential

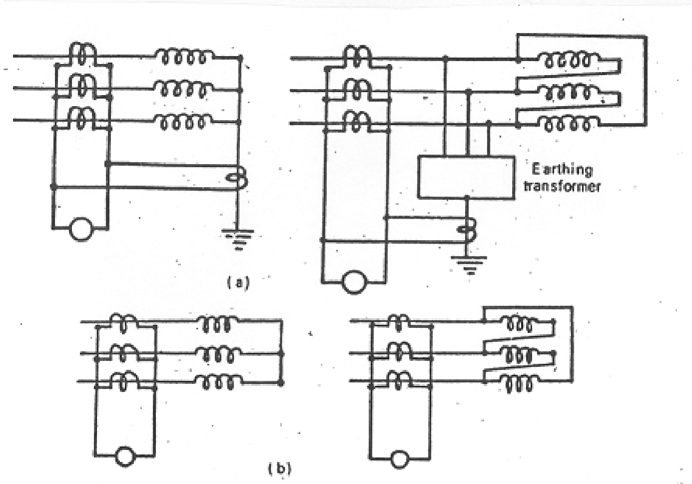


FIGURE 6.8 Restricted earth-fault protection: (a) neutral earthed within the protected zone; (b) neutral not earthed within the protected zone.

- A CT is fitted in each connection to the protected winding and CT secondaries are connected in parallel to the relay.
- For external faults have zero current in relay, for external faults have additive ZPS current into relay.

- Amount of winding protected determined by relay sensitivity. (and rating of earthing resistor if relevant)
- Following shows combined biased differential and REF:

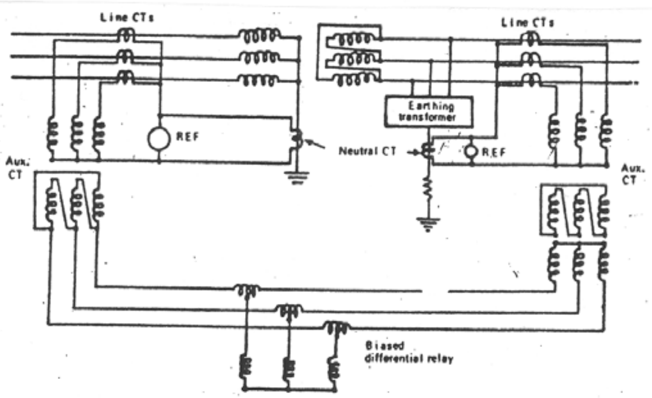


FIGURE 6.9 Differential and restricted earth-fault protection of a star/delta transformer.

Gas Actuated Relays

- When get fault in TX, gas is generated, slowly for incipient fault, violently for heavy fault → arc at fault causes heat → oil to decompose → gas.
- Following are relays which detect this gas:
  - Gas accumulator relay (Buchholz): commonly used on TXs with conservator and placed in connecting pipe. Contains two floats:

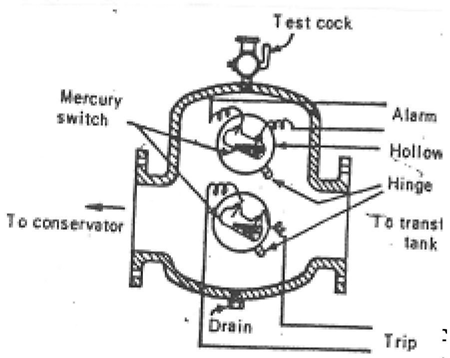


FIGURE 6.10 Buchholz relay.

    - c [illegible] Buchholz: as gas slowly b [illegible] ots to close alarm contact.
    - one for heavy faults in line with the pipe: get substantial gas flow which pushes this float over to close trip contact.
    - Leakage of oil will also cause these devices to operate.

  - Rate of pressure rise relay → rate of gas formation
  - Pressure relays and pressure device relays
  - Gas analysers which act on analysis of products of decomposition.
- No protection provided outside of TX.