USAID / SOUTH ASIA REGIONAL INITIATIVE FOR ENERGY (SARI/ENERGY)

June 7 – 19, 2010
Ahmedabad, Gujarat, India

SARI / Energy

CAPACITY BUILDING PROGRAM ON TRANSFORMERS

FOR

AFGHANISTAN TECHNICIANS

SARI / Energy

TRANSFORMER CONNECTIONS, PARALLEL OPERATION, LOSSES & EFFICIENCY AND FITTINGS & ACCESSORIES

PRESENTED

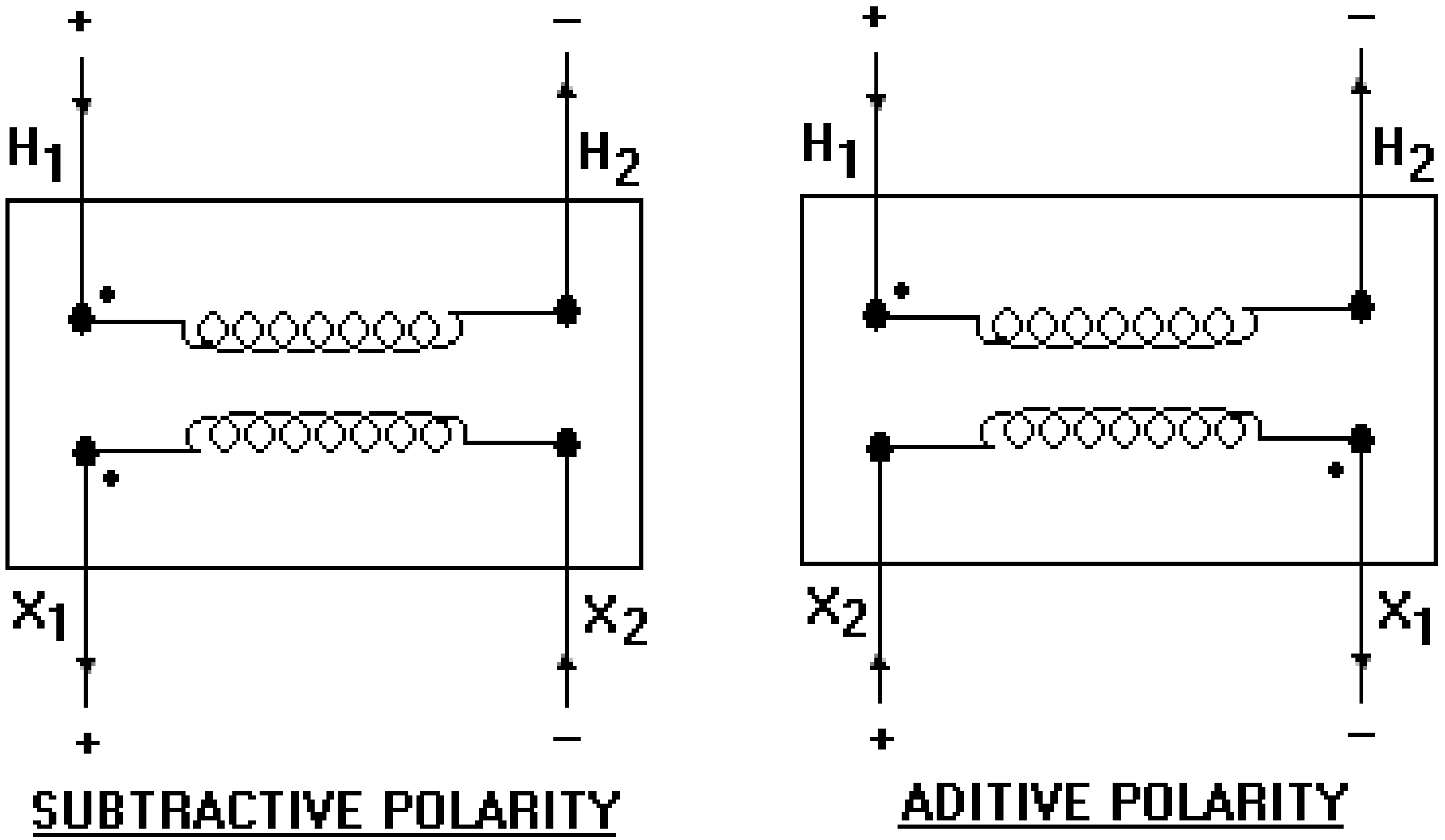
BY

PROF. V. G. PATEL

VECTOR GROUP OF TRANSFORMERS

POLYPHASE CONNECTIONS

- Delta – delta (mesh – mesh)
- Star – star
- Delta – star
- Star – delta
- Delta – zigzag
- Star – zigzag
- Open – delta (V – V or V)
- T – connection



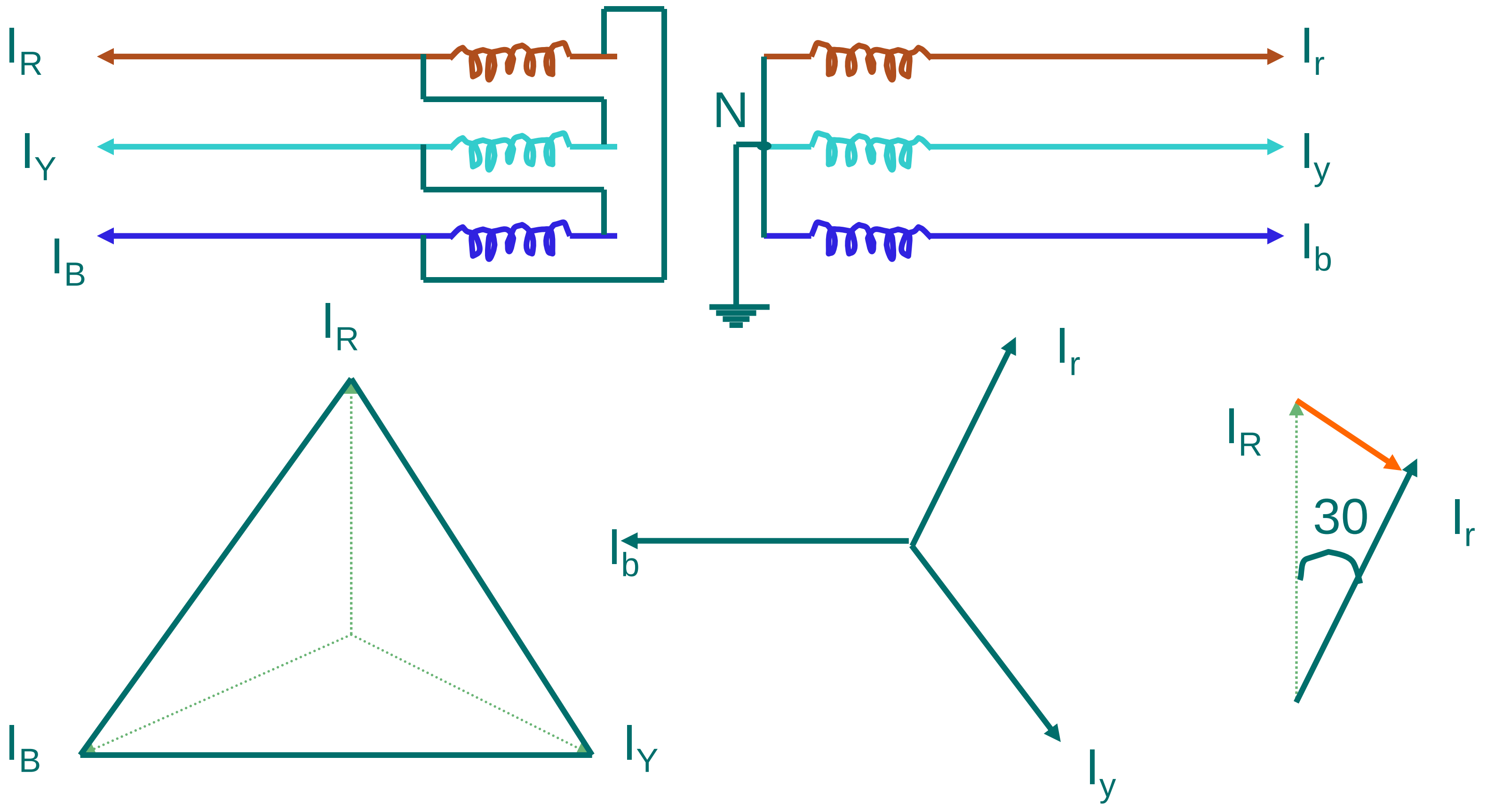
TRANSFORMER POLARITY DESIGNATION

High voltage (not primary) line emf is placed at 12 o'clock position and corresponding low voltage line emf position is noted. Low voltage line emf position denotes Hour hand of the clock and accordingly nomenclature is given (vector group is denoted).

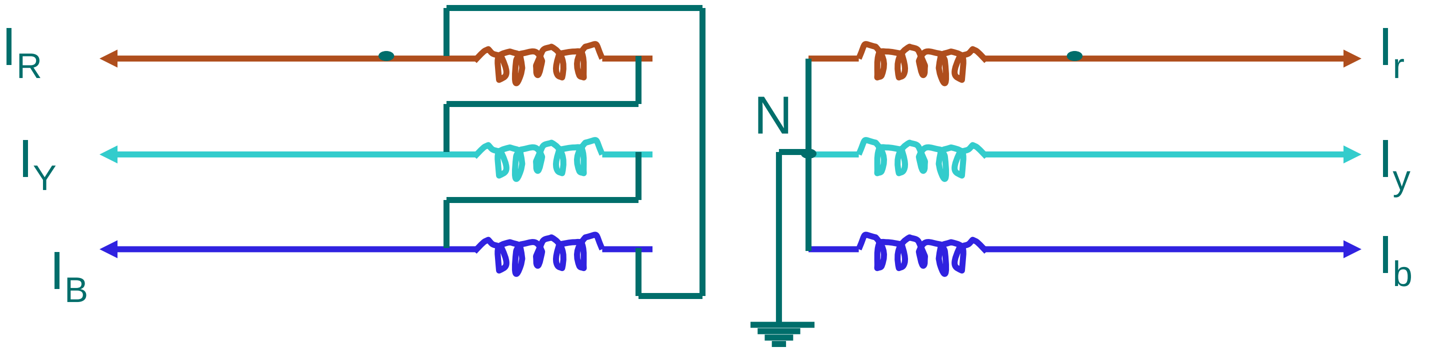
HV connection is denoted by capital letter, LV connection is denoted by small letter and corresponding LV line emf position is termed as HOUR hand of the clock and is denoted by suffix.

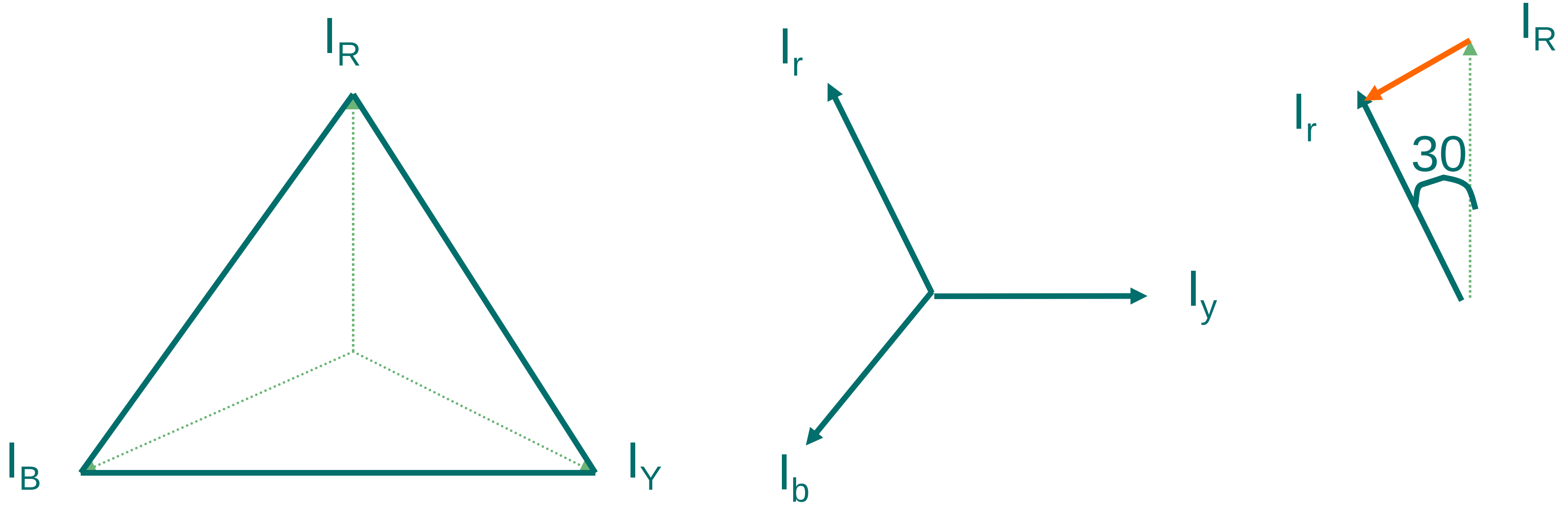
For HV delta connected and LV star connected, and LV line emf 30^0 leading is written as Dy_{11}

Dy1 CONNECTION

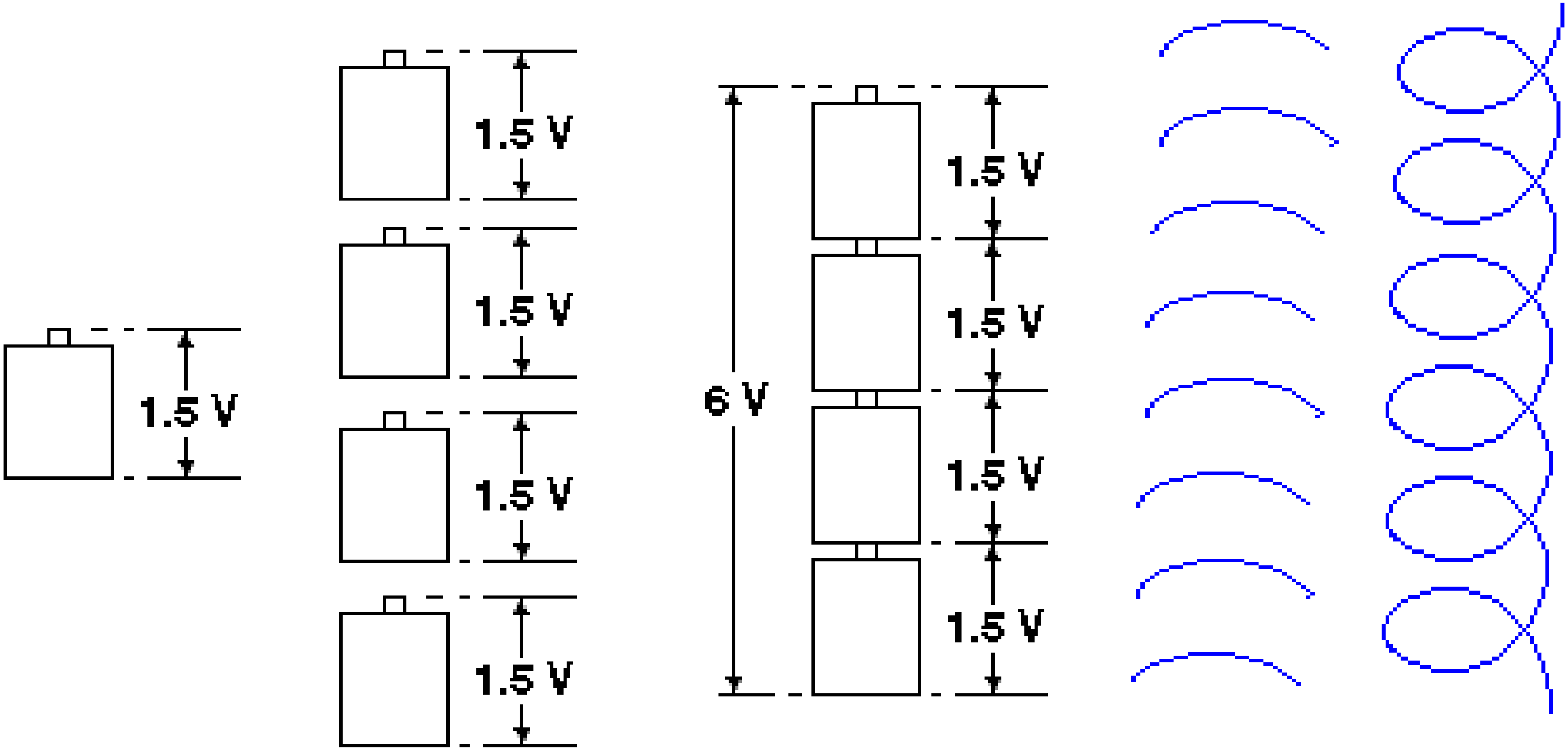


Dy_{11} CONNECTION

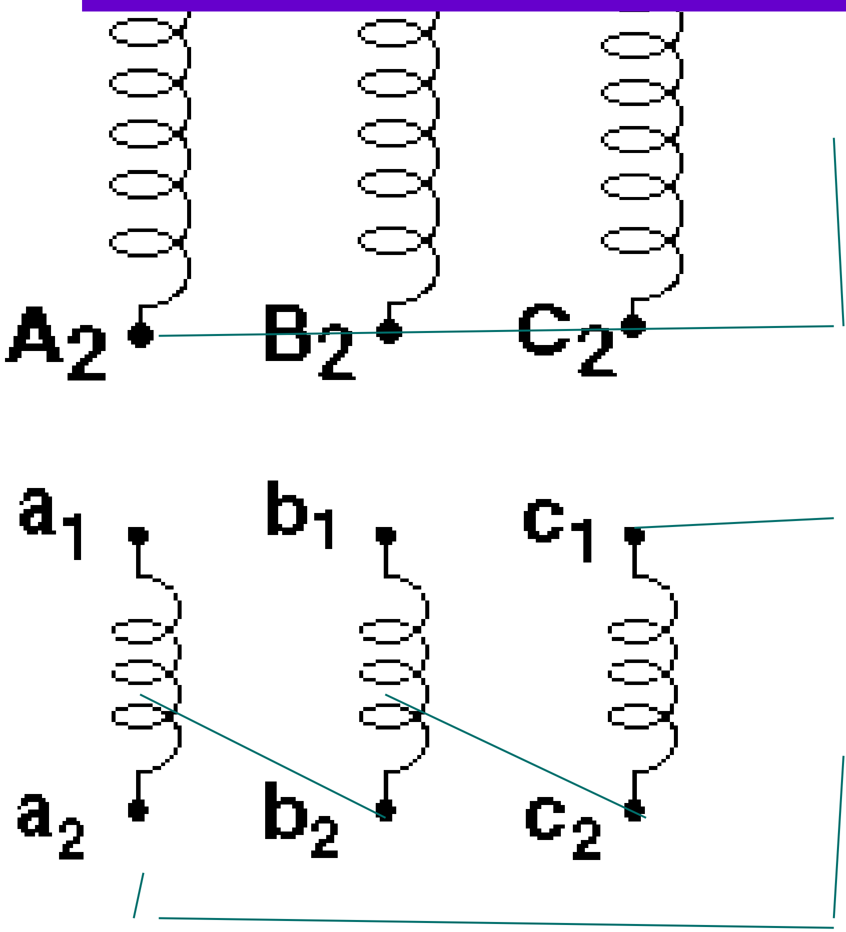


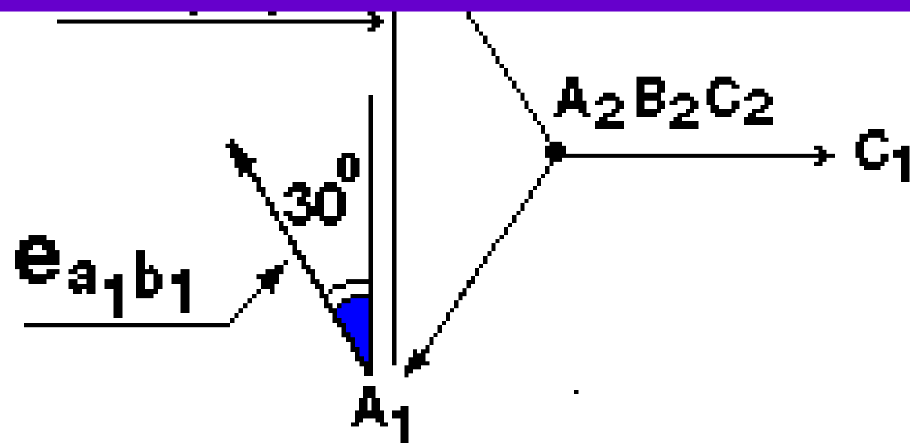


VECTOR GROUP OF TRANSFORMERS

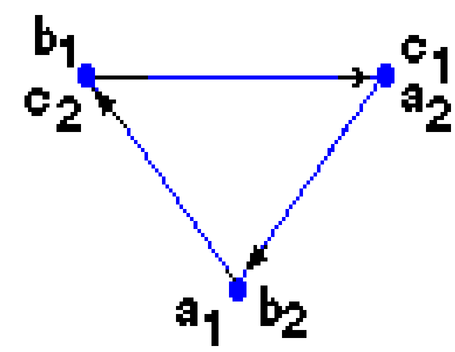


VECTOR GROUP OF TRANSFORMERS

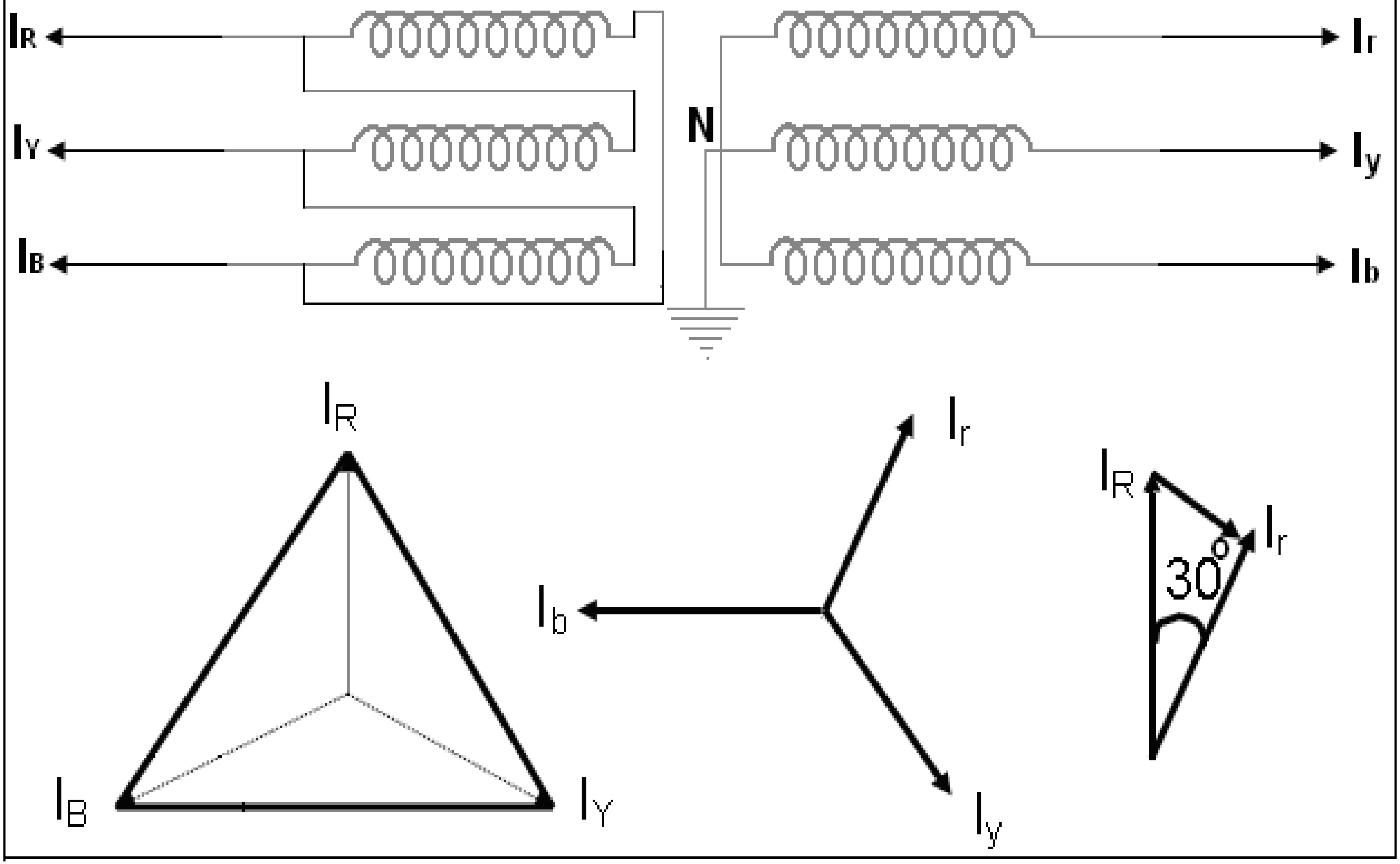




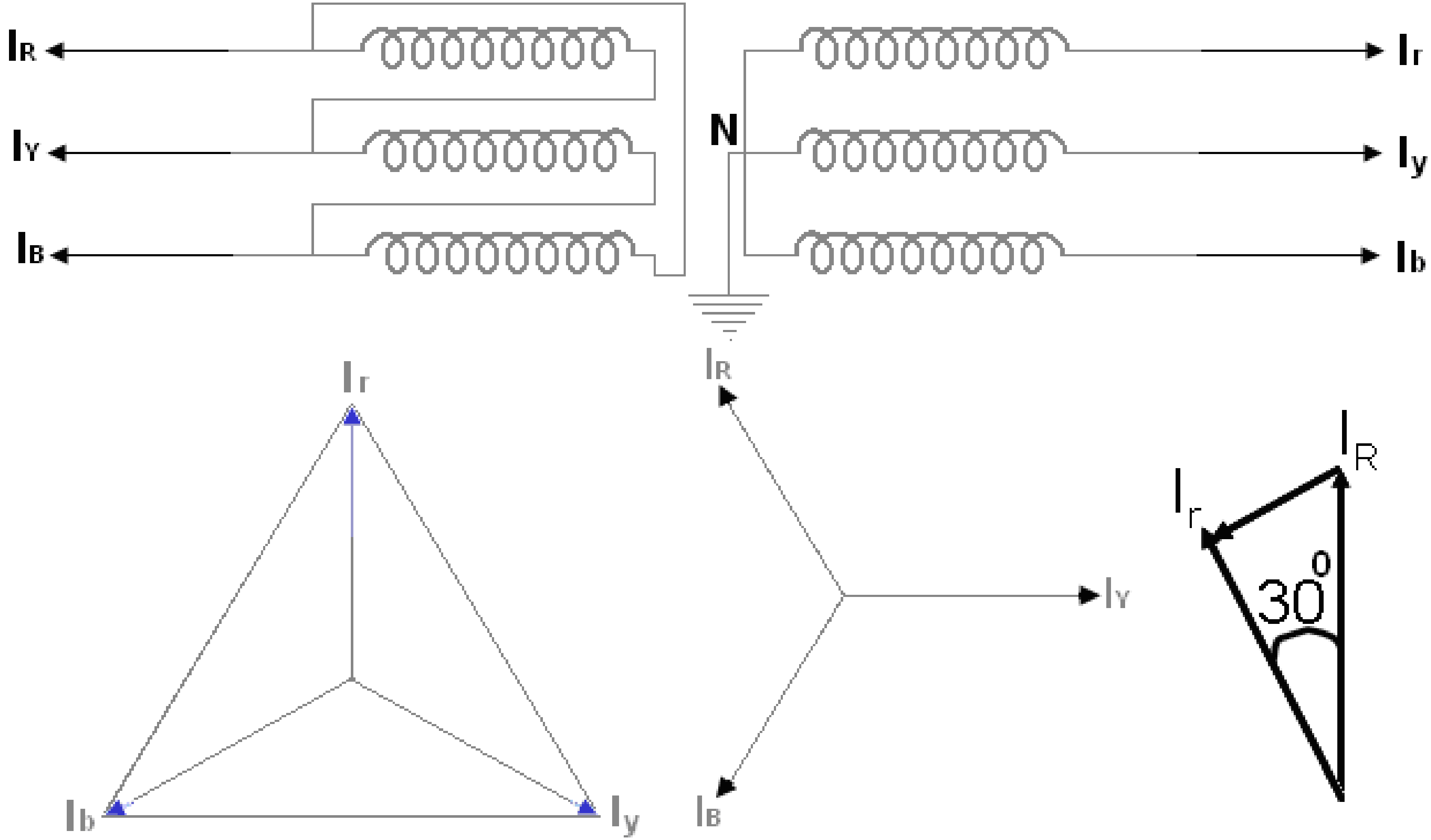
Yd11

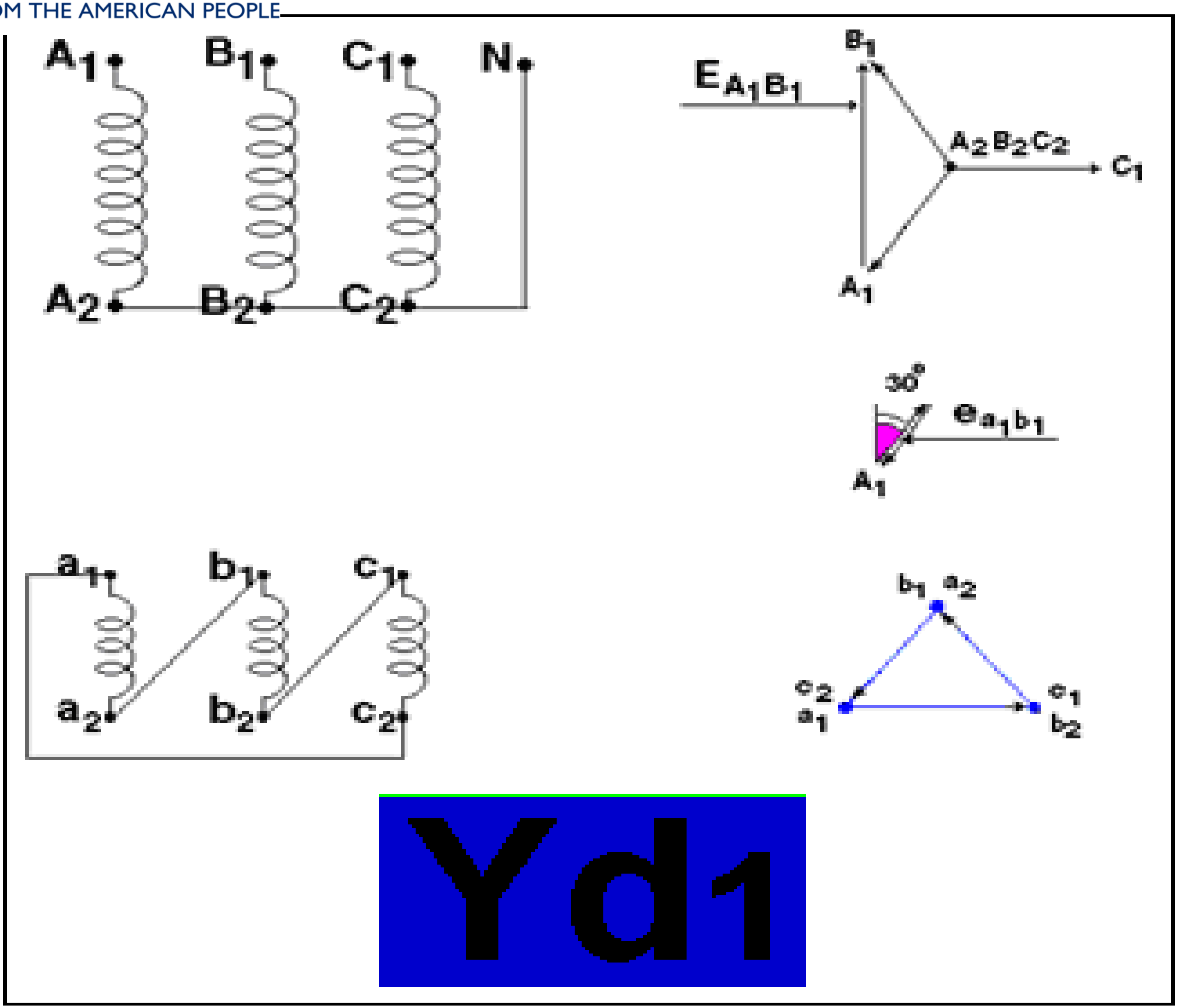


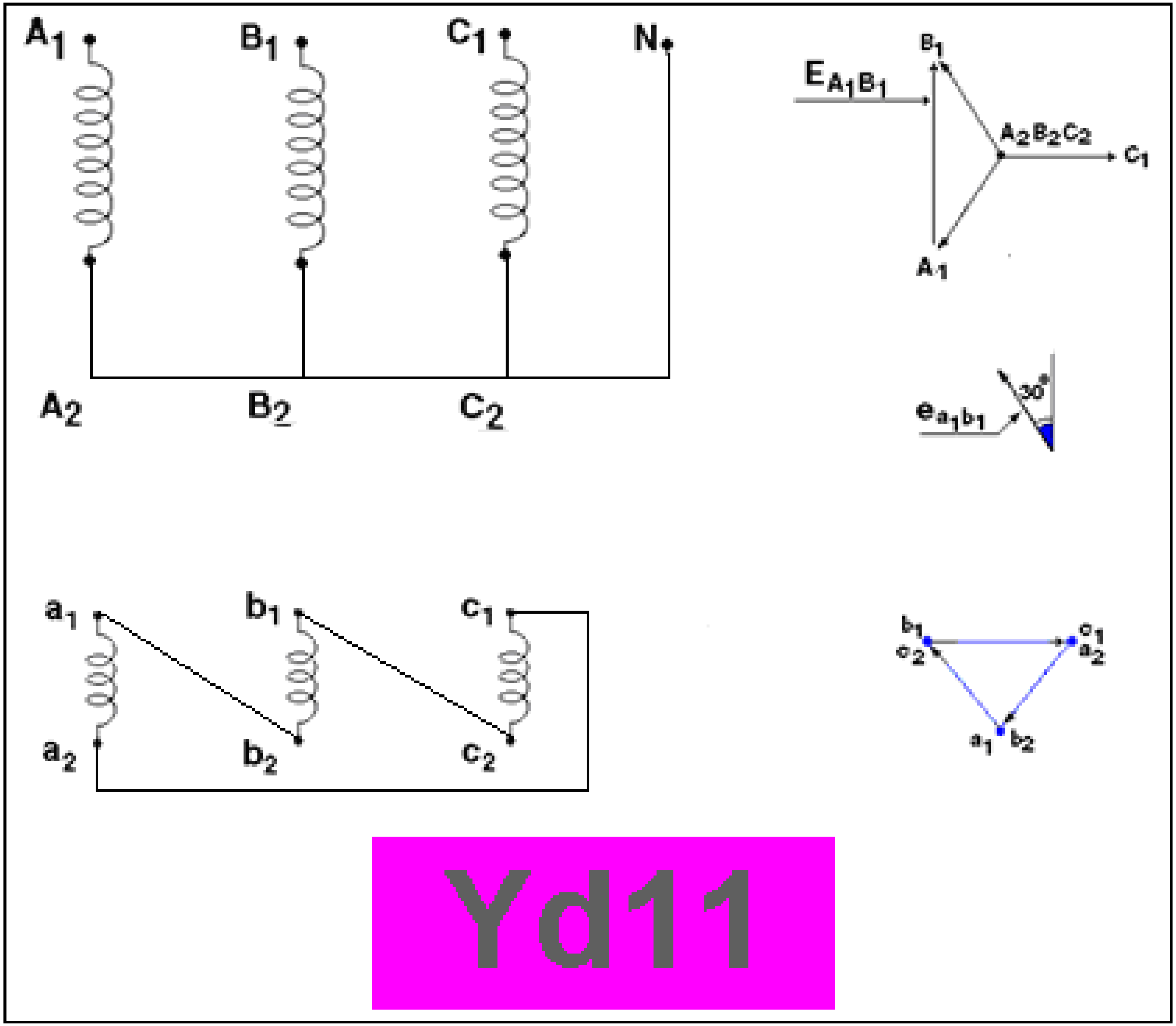
Dy1 CONNECTION



Dy11 CONNECTION

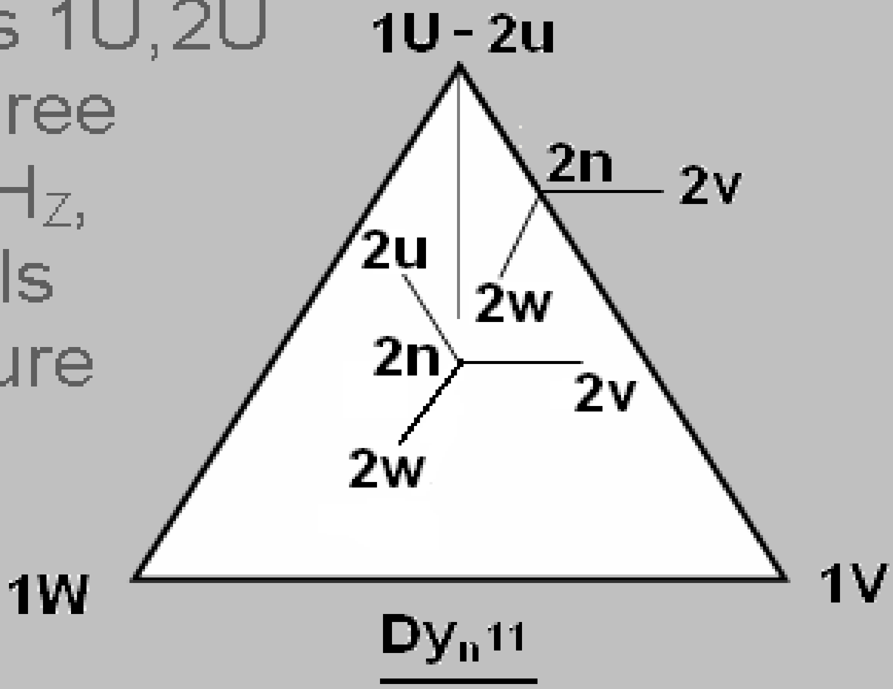



A1
B1
C1
N
A2
B2
C2
E A1B1
B1
A2 B2 C2
C1
A1
30°
e a1b1
A1
a1
b1
c1
a2
b2
c2
b1 a2
c2
a1
c1
b2
Yd1


A1
B1
C1
N
A2
B2
C2
EA1B1
B1
A2B2C2
C1
A1
ea1b1
30°
a1
b1
c1
a2
b2
c2
b1
c2
c1
a2
a1
b2
Yd11

VECTOR GROUP CHECK TEST

Connect terminals 1U,2U together. Apply three phase 415 V, 50 Hz, AC to HV terminals 1U,1V,1W. Measure voltages between terminals 1V-2V, 1V-2W & 1W-2V, 1W-2W.1V-2V & 1V-2W will be equal,while 1W-2V will be greater than 1W-2W for Dyn11 vector group.



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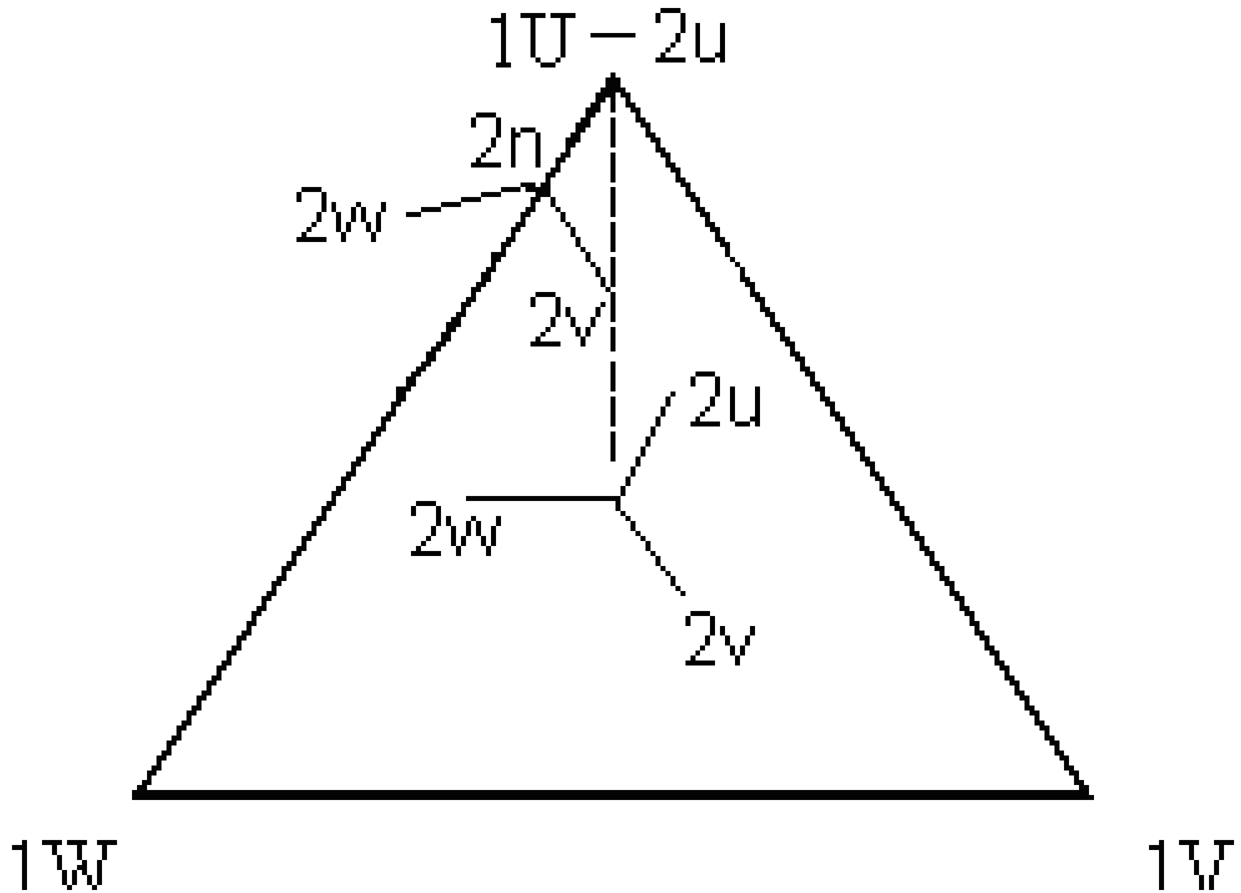
VECTOR GROUP CHECK TEST



Dyn1

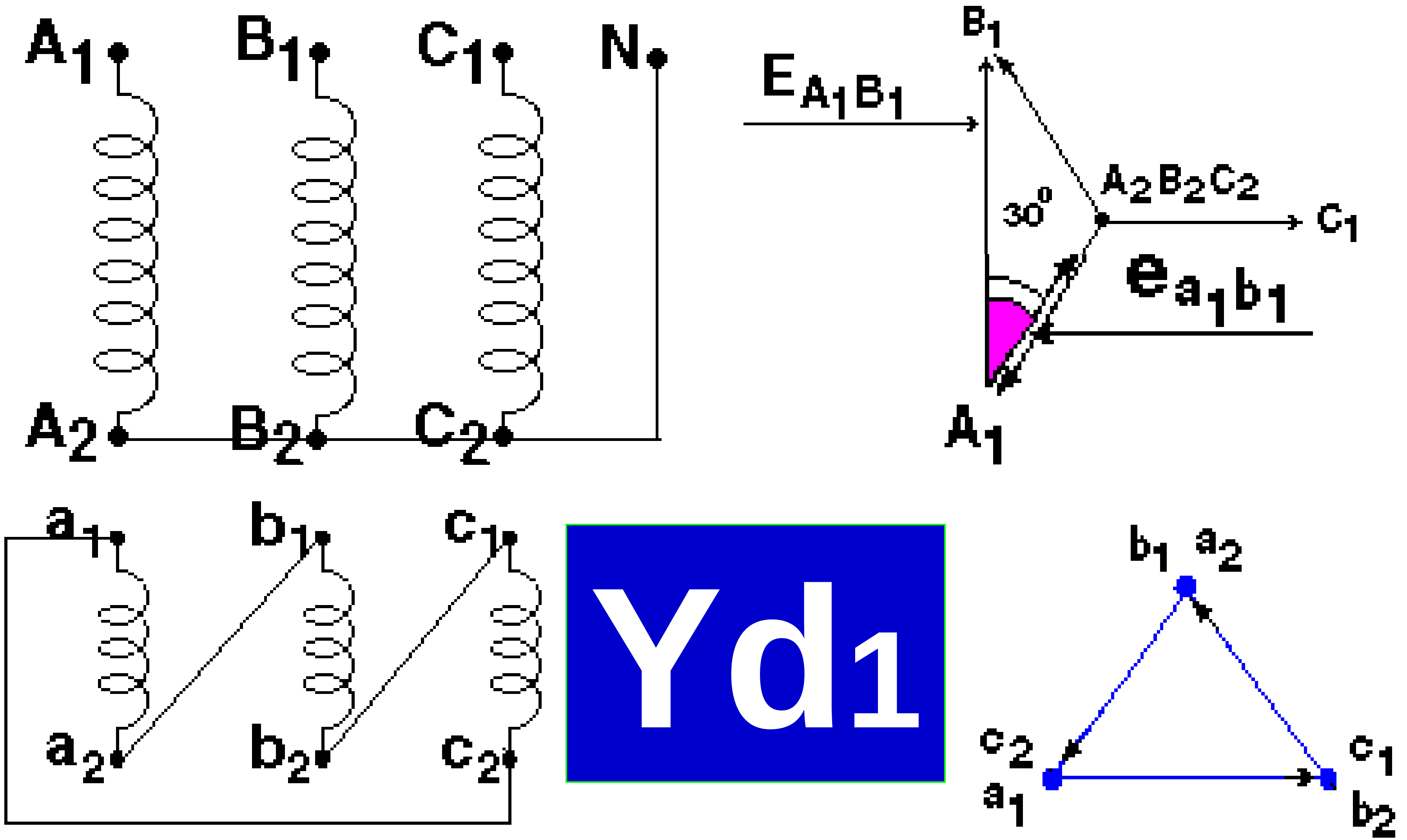
For parallel operation of transformers, vector group of both the transformers should be same.

Q - Can Dy11 and Dy1 vector group transformers be paralleled?

If answer is NO, why?

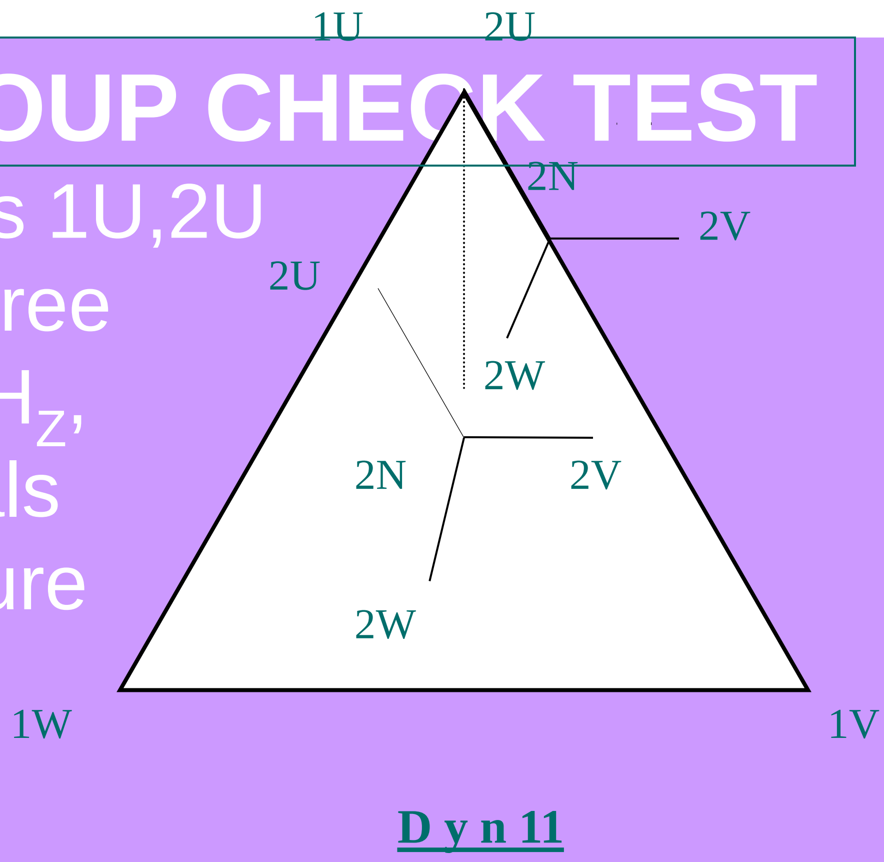
If answer is YES, how?

VECTOR GROUP OF TRANSFORMERS



VECTOR GROUP CHECK TEST

Connect terminals 1U,2U together. Apply three phase 415 V, 50 H_Z, AC to HV terminals 1U,1V,1W. Measure voltages between terminals 1V-2V, 1V-2W & 1W-2V, 1W-2W.1V-2V & 1V-2W will be equal,while 1W-2V will be greater than 1W-2W for Dyn11 vector group.



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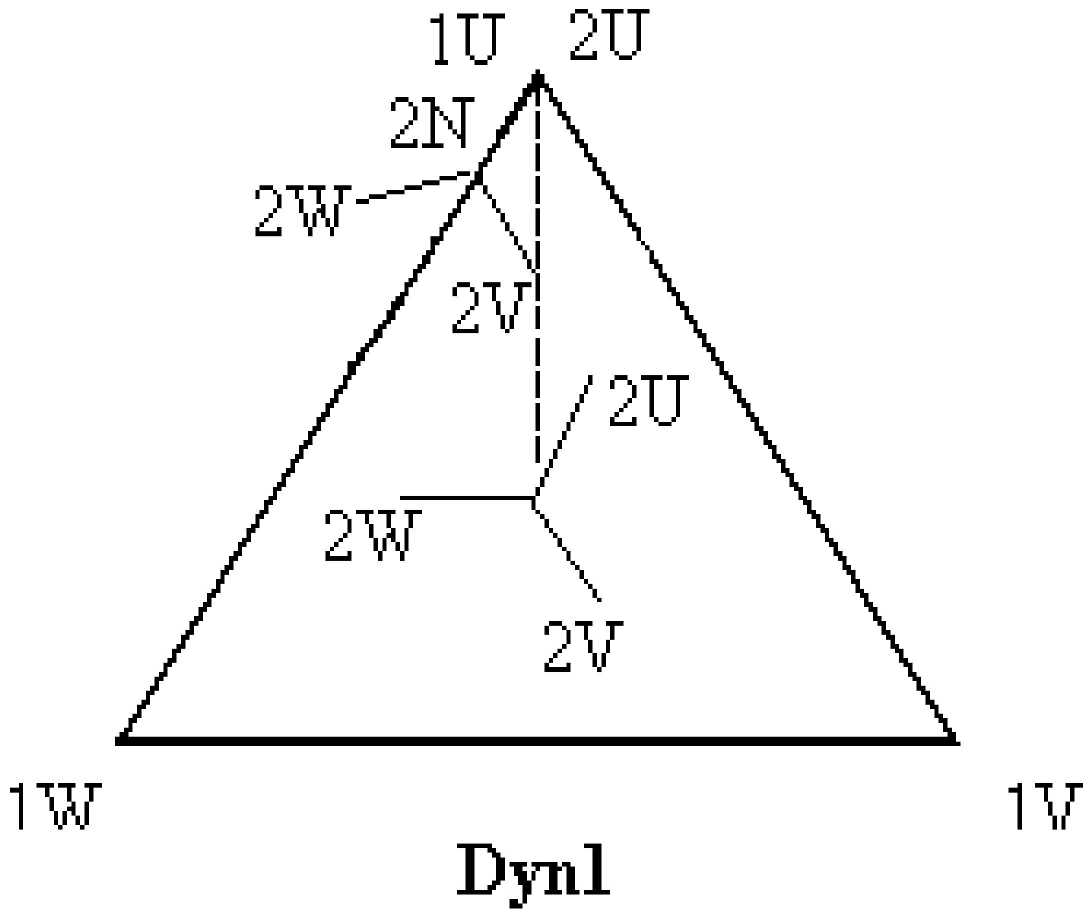
VECTOR GROUP CHECK TEST



For parallel operation of transformer, vector group of both the transfor-mers should be the same.

Q - Can Dy_{11} and Dy_1 vector group transformers be paralleled?

If answer is NO, why?

If answer is YES, how?

PARALLEL OPERATION OF TRANSFORMERS

For supplying a load in excess of the rating of an existing transformer, two or more transformers may be connected in parallel with the existing transformer. It is usually economical to install another transformer in parallel instead of replacing the existing transformer by a single larger unit. The cost of a spare unit in the case of two parallel transformers (of equal rating) is also lower than that of a single large transformer.

In addition, it is preferable to have a parallel transformer for the reason of reliability. With this, at least half the load can be supplied with one transformer out of service. For parallel connection of transformers, primary windings of the transformers are connected to source bus-bars and secondary windings are connected to the load bus-bars. There are various conditions that must be fulfilled for the successful parallel operation of transformers. These are as follows:

1. The line voltage ratios of the transformers must be equal (on each tap): If the transformers connected in parallel have slightly different voltage ratios, then due to the inequality of induced emfs in the secondary windings, a circulating current will flow in the loop formed by the secondary windings under the no-load condition, which may be much greater than the normal no-load current. The current will be quite high as the leakage impedance is low. When the secondary windings are loaded, this circulating current will tend to produce unequal loading on the two transformers, and it may not be possible to take the full load from this group of two parallel transformers (one of the transformers may get overloaded).

2. The transformers should have equal per-unit leakage impedances and the same ratio of equivalent leakage reactance to the equivalent resistance (X/R): If the ratings of both the transformers are equal, their per-unit leakage impedances should be equal in order to have equal loading of both the transformers. If the ratings are unequal, their per-unit leakage impedances based on their own ratings should be equal so that the currents carried by them will be proportional to their ratings. In other words, for unequal ratings, the numerical (ohmic) values of their impedances should be in inverse proportion to their ratings to have current in them in line with their ratings.

A difference in the ratio of the reactance value to resistance value of the per- unit impedance results in a different phase angle of the currents carried by the two paralleled transformers; one transformer will be working with a higher power factor and the other with a lower power factor than that of the combined output. Hence, the real power will not be proportionally shared by the transformers.

3. The transformers should have the same polarity: The transformers should be properly connected with regard to their polarity. If they are connected with incorrect polarities then the two emfs, induced in the secondary windings which are in parallel, will act together in the local secon-dary circuit and produce a short circuit.

The previous three conditions are applicable to both single-phase as well as three-phase trans-formers. In addition to these three conditions, two more conditions are essential for the parallel operation of three-phase transformers:

4. The transformers should have the same phase sequence: The phase sequence of line voltages of both the transformers must be identical for parallel operation of three-phase transformers. If the phase sequence is an incorrect, in every cycle each pair of phases will get short-circuited.

5. The transformers should have the zero relative phase displacement between the secondary line voltages: The transformer windings can be connected in a variety of ways which produce different magnitudes and phase displacements of the secondary voltage. All the transformer connections can be classified into distinct vector groups. Each vector group notation consists of first an uppercase letter denoting HV connection, a second lowercase letter denoting LV connection, followed by a *clock number* representing LV winding's phase displacement with respect to HV winding (at 12 o'clock). There are four groups into which all possible three-phase connections can be classified:

Group 1: Zero phase displacement

(Yy_O, Dd_O, Dz_O)

Group 2: 180^0 phase displacement

(Yy_6, Dd_6, Dz_6)

Group 3: -30^0 phase displacement

(Yd_1, Dy_1, Yz_1)

Group 4: $+30^0$ phase displacement

(Yd_{11}, Dy_{11}, Yz_{11})

In above notations, letters y (or Y), d (or D) and z represent star, delta and zigzag connections respectively. In order to have zero relative phase displacement of secondary side line voltages, the transformers belonging to the same group can be paralleled. For example, two transformers with Yd_1 and Dy_1 connections can be paralleled. The transformers of groups 1 and 2 can only be paralleled with transformers of their own group. However, the transformers of groups 3 and 4 can be paralleled by reversing the phase sequence of one of them. For example, a transformer with Yd_{11} connection (group 4) can be paralleled with that having Dy_1 connection (group 3) by reversing the phase sequence of both primary and secondary terminals of the Dy_1 transformer.

TRANSFORMERS

LOSSES AND EFFICIENCY

EFFICIENCY

EFFICIENCY

What is Efficiency?

- Efficiency of any operation is a measure of useful work output compared to the work input.

Efficiency of the Transformer

Transformers are electrical equipment designed to convert one alternating current voltage to another. They are essential in electrical distribution systems and are widely used to raise voltages for transmission over long distances and then reduce the voltage of the power line to a voltage suitable and safe for facility equipment (415 or 433 volts).

Efficiency of the Transformer

Efficiency = Useful electrical energy output
Total electrical energy input

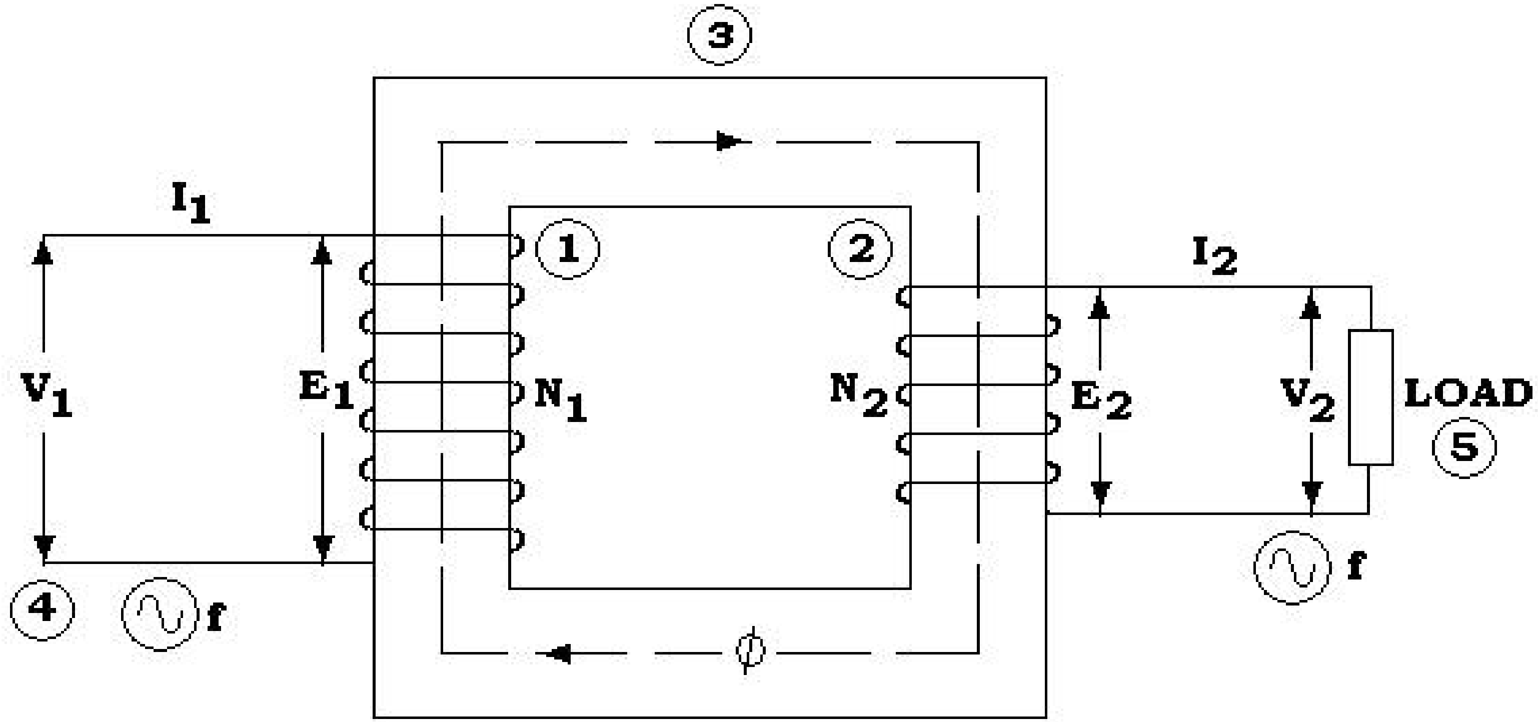
%η = (Output / Input) **x** 100

= [Output / (Output + Losses)] **x** 100

= [(Input – losses) / (Input)] **x** 100

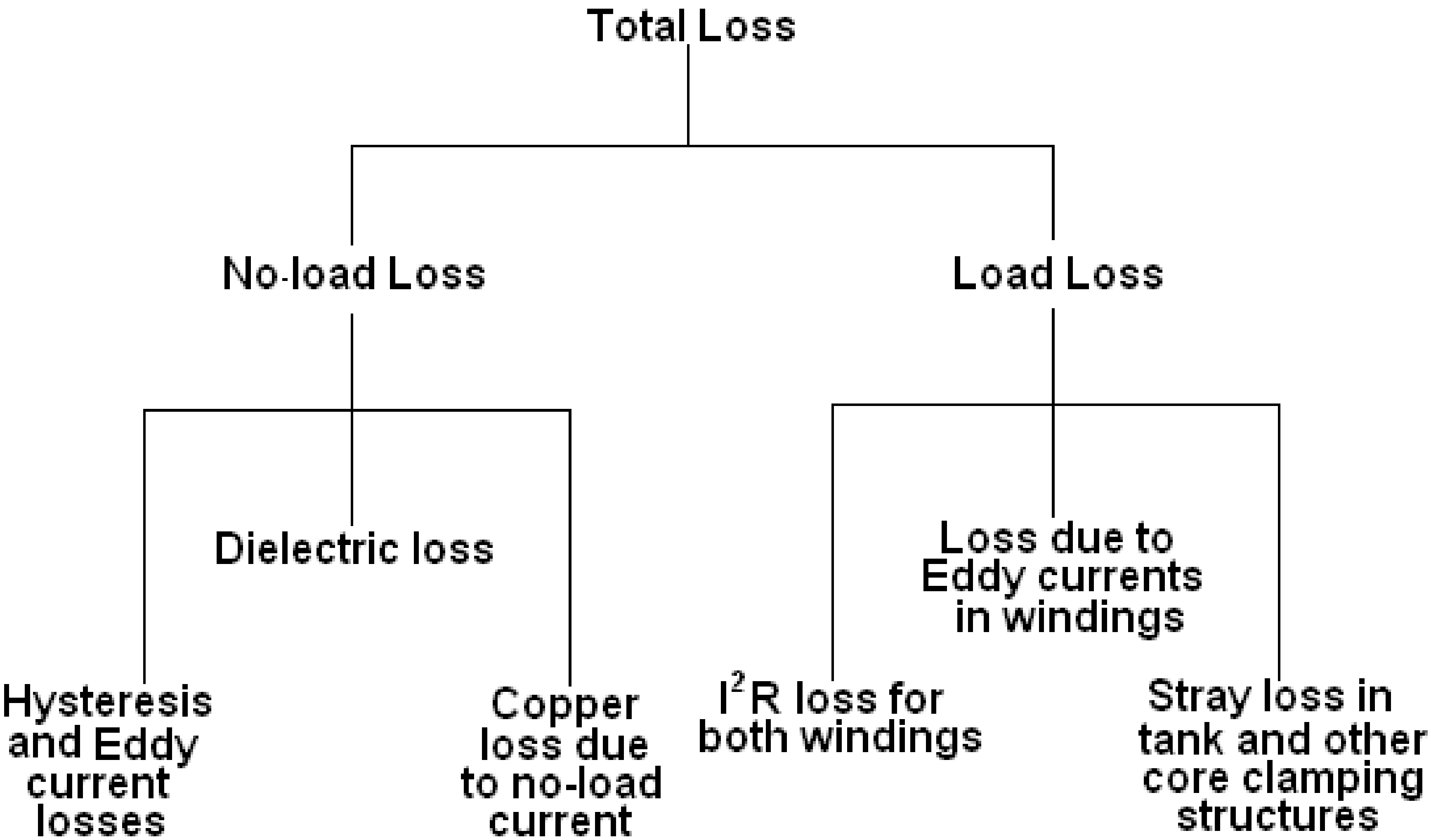
The losses in a transformer are essentially very small and the efficiency of large transformers is over 99%. Even with small transformers, efficiencies of 97% or 98% are usual. There are two main losses in a transformer, namely, the iron losses and the copper losses. The iron losses are normally taken as constant at all loads, whereas the copper loss is proportional to the square of the load.

When the load on the transformers decreases, the no-load losses in these lightly loaded transformers increase (as a percentage), causing a loss of efficiency.



1. Primary winding with N1 turns
2. Secondary winding with N2 turns
3. Core with magnetic flux ϕ
4. Supply
5. Load

PRINCIPLE OF A SINGLE-PHASE TRANSFORMER


Total Loss
No-load Loss
Load Loss
Dielectric loss
Hysteresis and Eddy current losses
Copper loss due to no-load current
Loss due to Eddy currents in windings
I2R loss for both windings
Stray loss in tank and other core clamping structures

Reducing losses can increase transformer efficiency. There are two components that make up transformer losses. The first is “core” loss (also called no-load loss), which is the result of the magnetizing and de-magnetizing of the core during normal operation. Core loss occurs whenever the transformer is energized; core loss does not vary with load. Amorphous iron, a new type of core material that reduces core loss, has recently become available. Developed in Europe, amorphous iron is made of rapidly cooled molten metal alloy. Amorphous iron is expensive but reduces core loss to less than 30% those of conventional steel cores.

An alternative less expensive core material is silicone steel, which has losses higher than amorphous iron, but less than standard carbon steel.

The second component of loss is called coil or load loss; because the efficiency losses occur in the primary and secondary coils of the transformer. Coil loss is a function of the resistance of the winding materials and varies with the load on the transformer.

Transformer efficiency will be maximum when Load Losses = Iron Losses

The choice of winding material-copper or aluminum-affects efficiency. Copper is a better electrical conductor than any other metal except silver. Electricity flowing through copper wires meets far less resistance than it does in aluminum or steel wires of the same diameter. Copper wires result in lower electrical losses, which appear as unwanted heat. Engineers call these resistive, or I^2R, losses. Use of copper windings minimizes transformer full - load losses and may permit smaller cores, minimizing core (no-load) losses. Another way to reduce transformer losses is to use larger diameter wires that allow current to flow more easily.

What is the condition of loading for maximum efficiency and its significance?

The maximum efficiency of a transformer occurs at a load factor at which the iron losses are equal to the copper losses.

This is the condition for maximum efficiency of a transformer.

In other words, for maximum efficiency,

Core Loss = Short-circuit Loss.

Iron Loss = Copper loss.

Efficiency of a power transformer is to be determined on the basis of test results of O.C. test and S.C. test.

Data: Transformer ratings: 11/0.44 kV, 50 Hz, 3-phase, Delta-star, 300 kVA.

Results O.C. Test:

No-load current 21.1 A at 440 V.

At L.V. side with loss 1.3 kW.

Results of S.C. Test:

Reading from HV side: 630 V, 15.7 A, Loss 3.08 kW at winding temperature 30^0C.

Calculate efficiency at full load and P.F. 0.8 lag.

From O.C. Test (No-load test):

No-load loss Pi =1.30 kW

From S.C. Test:

Full load copper loss Pi =3.08 kW

% Efficiency = $\frac{Output}{Input} X100$ = $\frac{Input - Losses}{Input} X100$

$$\%\eta = \frac{KS\cos\phi}{KS\cos\phi + P_i + K^2 P_c}$$

$$=1 - \frac{P_i + K^2 P_c}{KS\cos\phi + P_i + K^2 P_c}$$

Let Pc = Full load copper loss

Pi = No-load loss

K = Load Factor = $\frac{Actual - load}{Full - load}$

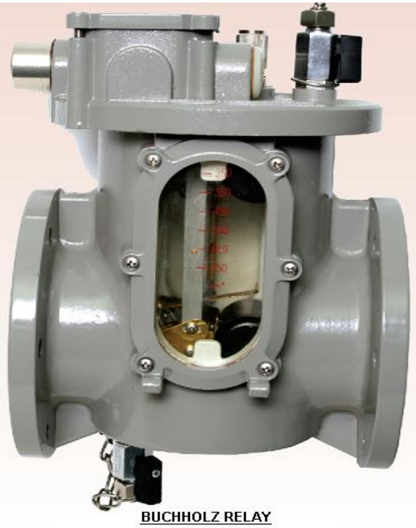
S=Rated kVA loading

In this problem K=1

$$\%\eta = 1 - \frac{1.3 + 3.08}{(300\,X\,0.8) + (1.3 + 3.08)}$$

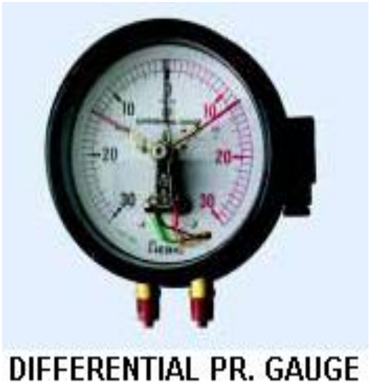
$$= 1 - \frac{4.38}{240 + 4.38}$$

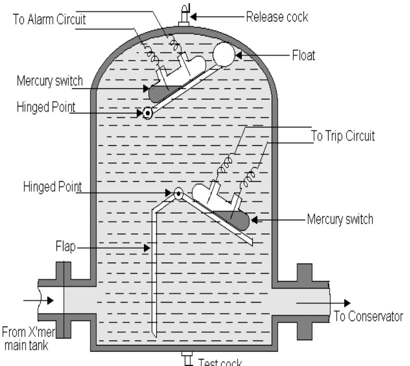
= (1-0.018) X100=98%. **---→Ans.**



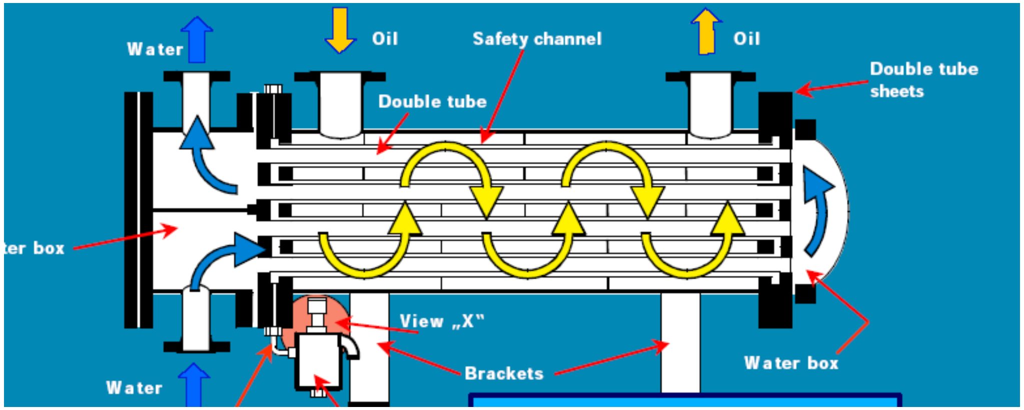
TRANSFORMER FITTINGS AND ACCESSORIES

Silica gel breather

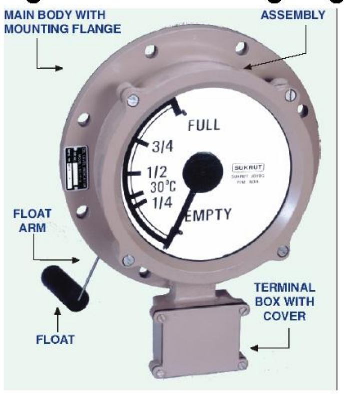




Buchholz Relay



Magnetic oil level gauge

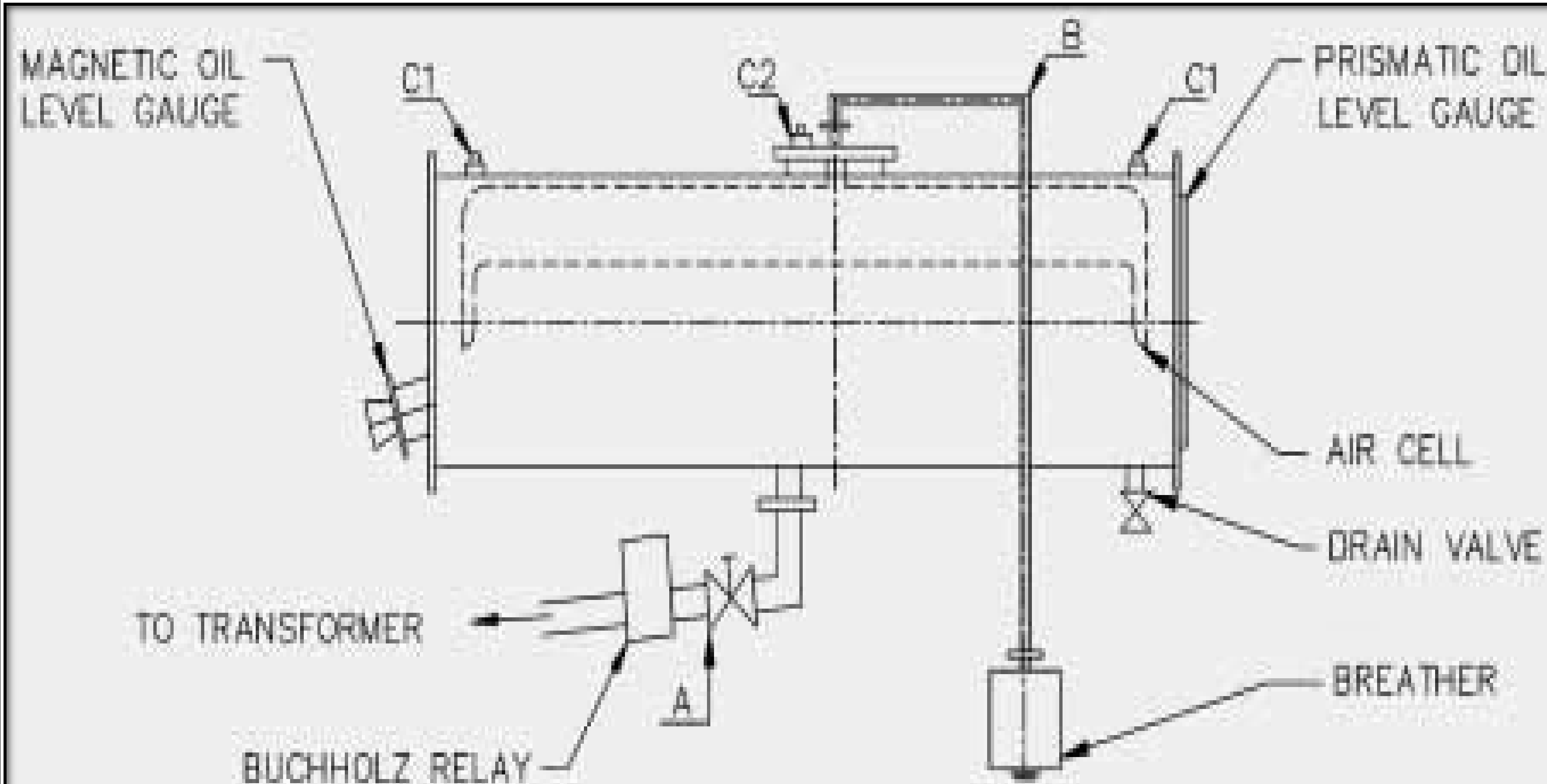


Fittings & Accessories

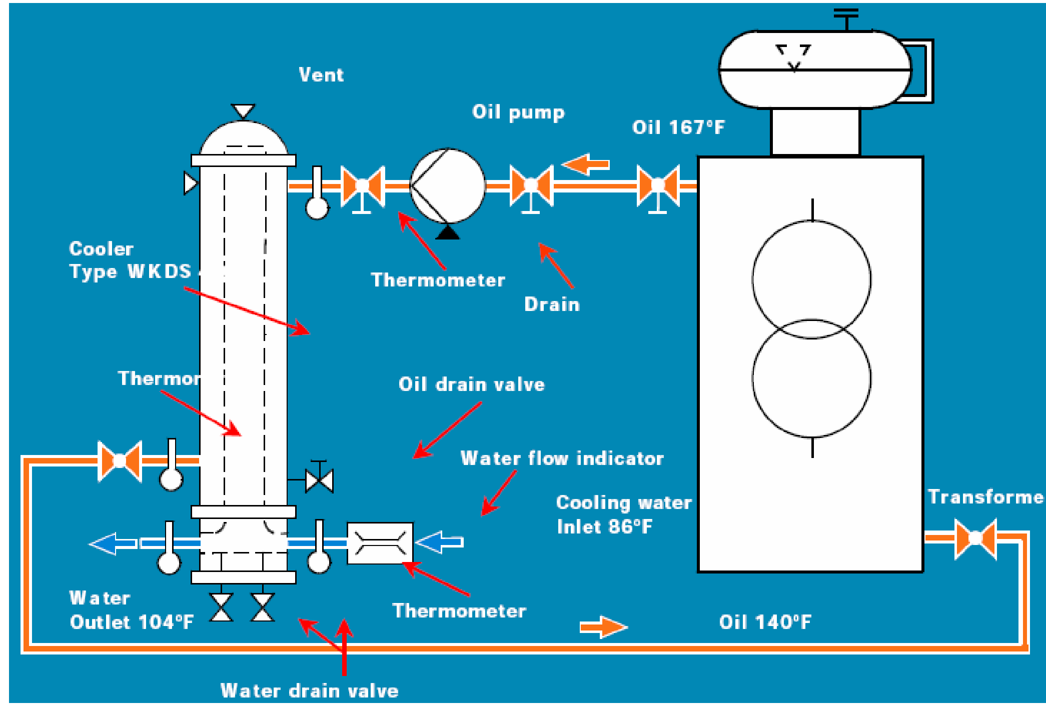
- Silicagel Breather*
- Prismatic Oil Level Gauge*
- M. O. G.*
- O. T. I. & W. T. I.
- Bushings*
  - H.V
  - L.V.
  - Tertiary
- OLTC*
- Off Circuit Tap Switch*
- RTCC Panel*

- Marshalling Box
- Explosion Vent
- Pressure Relief Valve
- Buchholz Relay
- Sudden Pressure Relay
- Heat Exchanger
- Oil Pump
- Temperature Gauge
- Pressure Gauge
- Oil Flow Indicator
- Water Flow Indicator
- Pressure Vacuum Bleeder

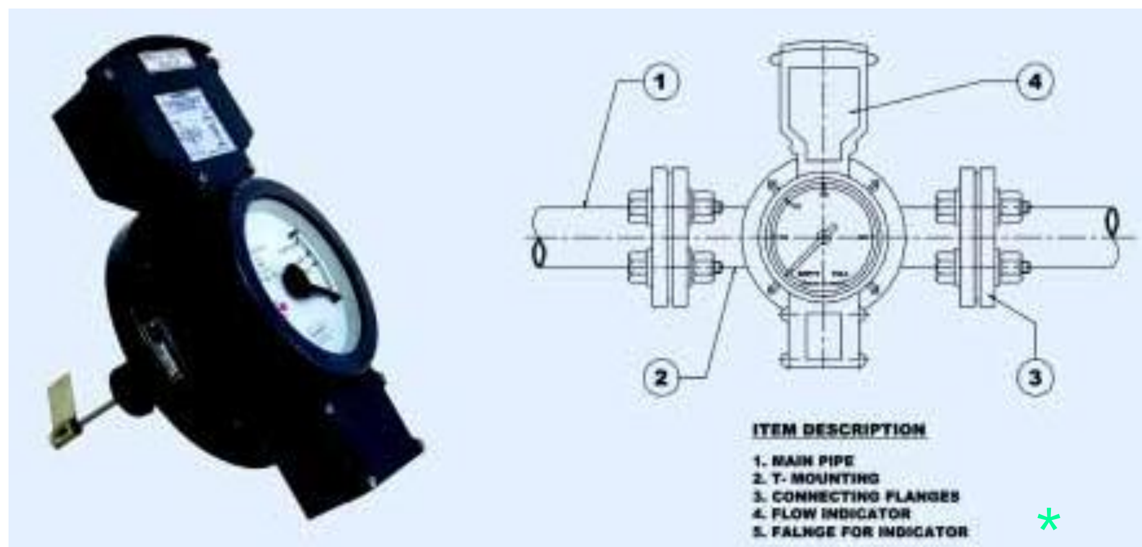
- Current Transformers*
  - Bushing CT
  - HV/LV CT
  - Neutral CT
- Thermo Syphon Filter*
- Bimetallic connector*
- Valves
  - Globe valve
  - Gate valve
  - Butterfly valve
  - Non-return valves



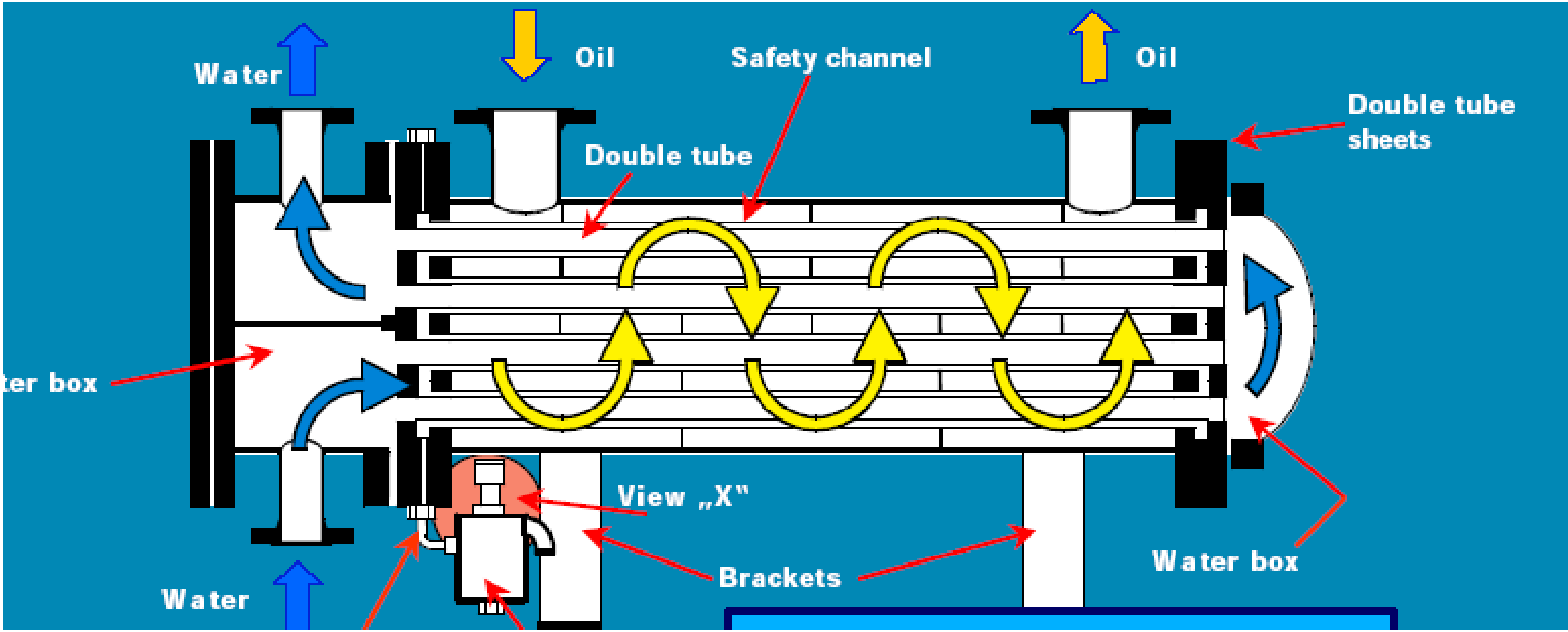
ARRANGEMENT OF MAGNETIC OIL LEVEL GAUGE, BREATHER, PRISMATIC OIL LEVEL GAUGE AND BUCHHOLZ RELAY



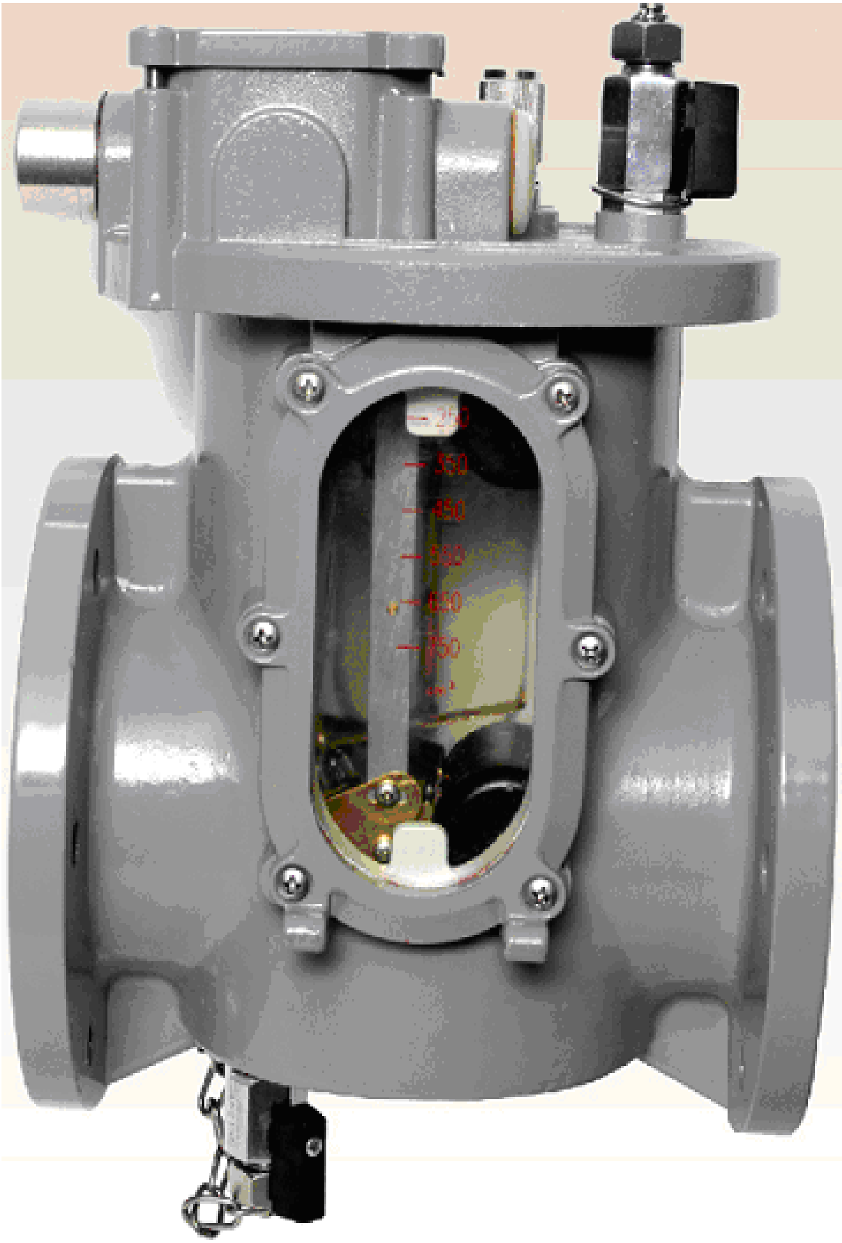
WATER FLOW INDICATOR



OIL FLOW INDICATOR



DIFFERENTIAL PR. GAUGE



BUCHHOLZ RELAY

BUCHHOLZ RELAY

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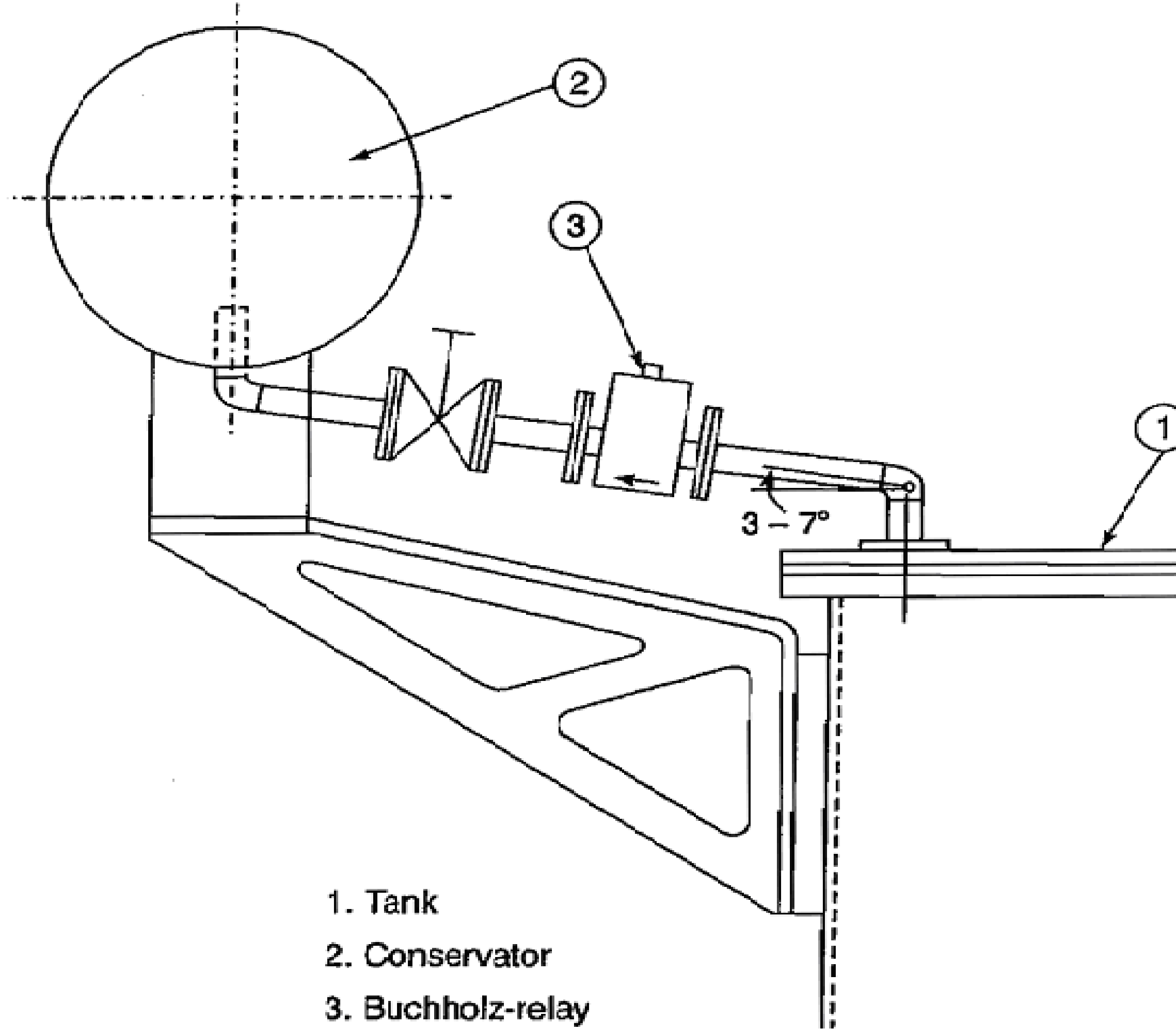
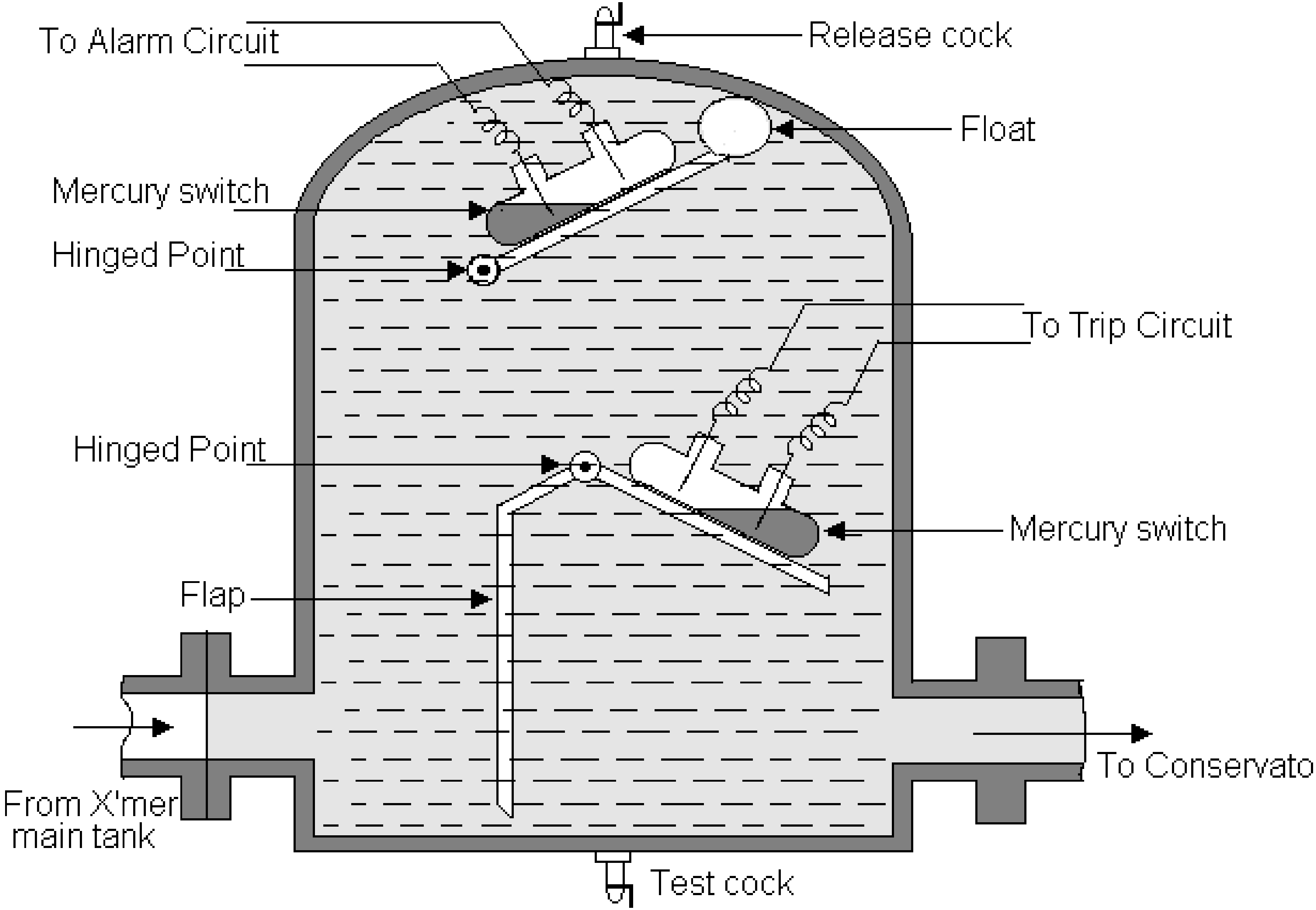
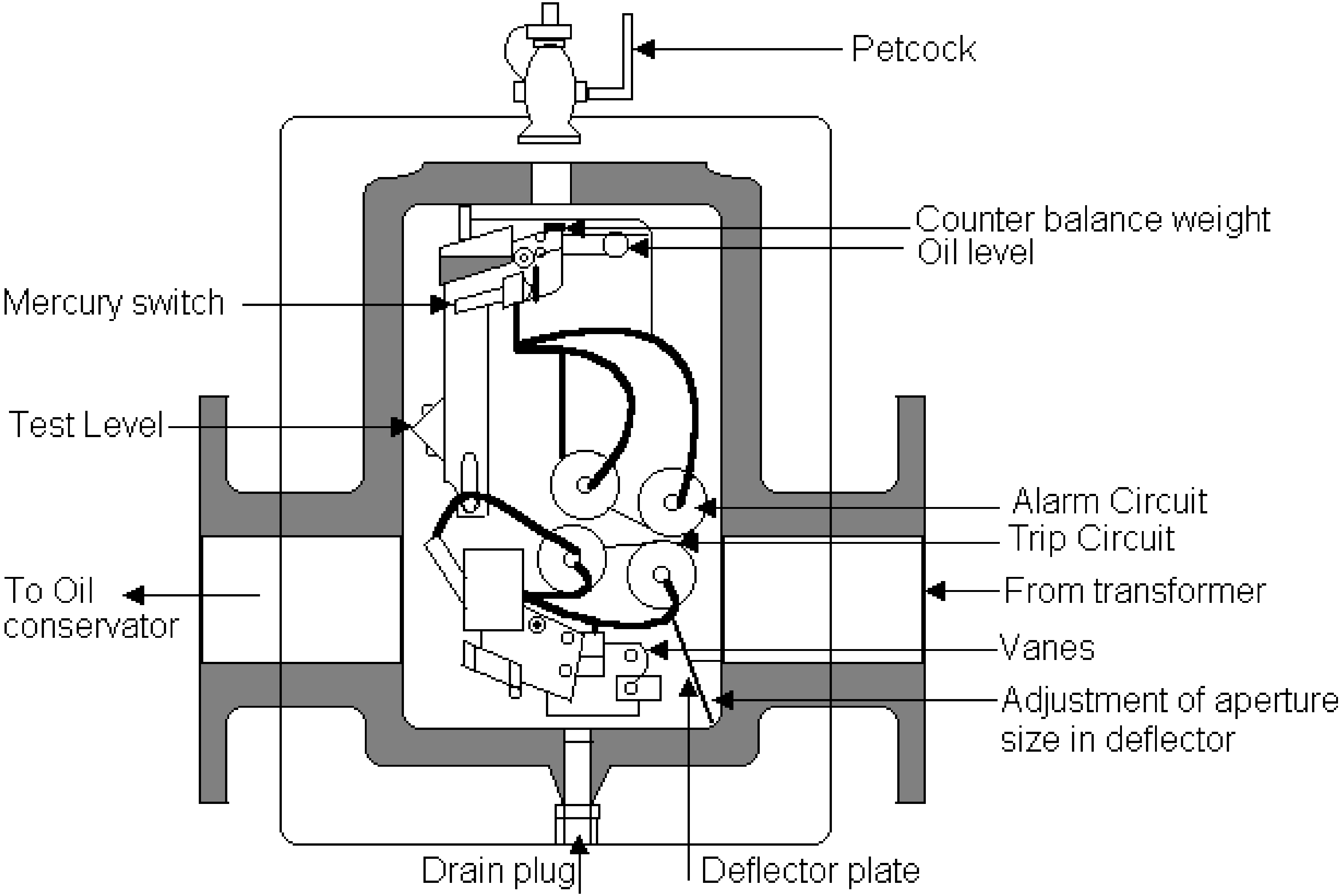


Method of mounting Buchholz-relay on transformer



Buchholz Relay



Modern Buchholz Relay

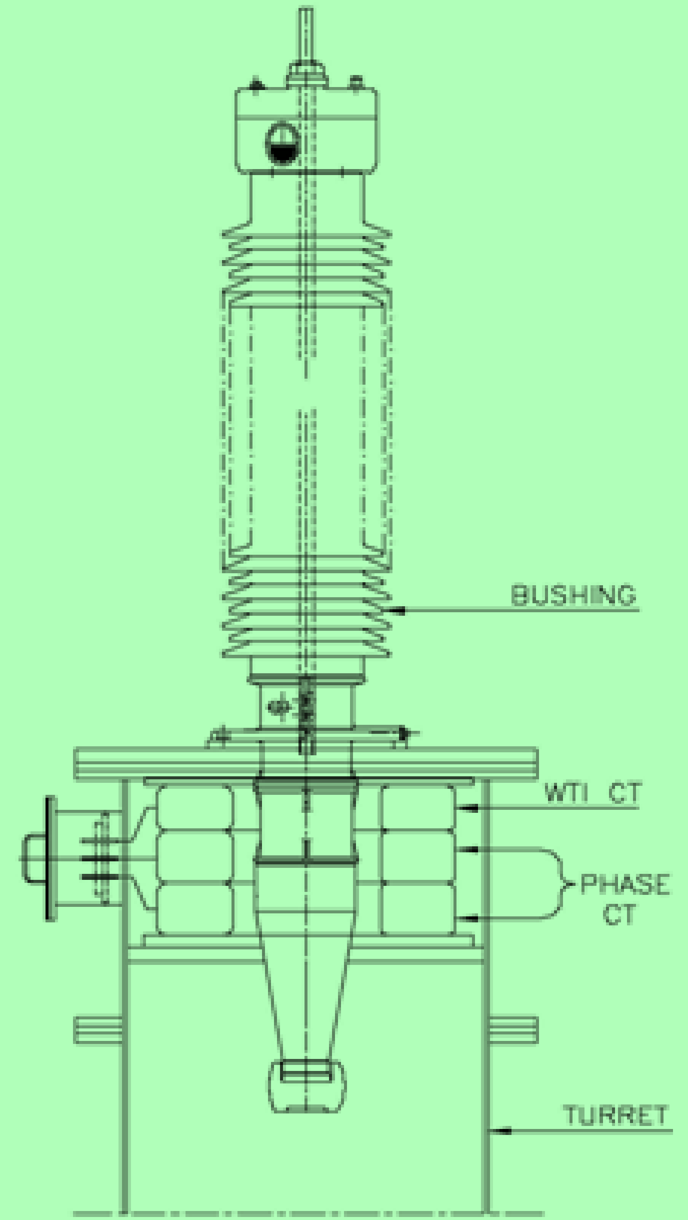

CONSER-
VATOR
TANK
FANS
RADIATOR

AIR CELL

Silica gel breather


SILICA GEL BREATHER

*



BUSHING CT ASSEMBLY

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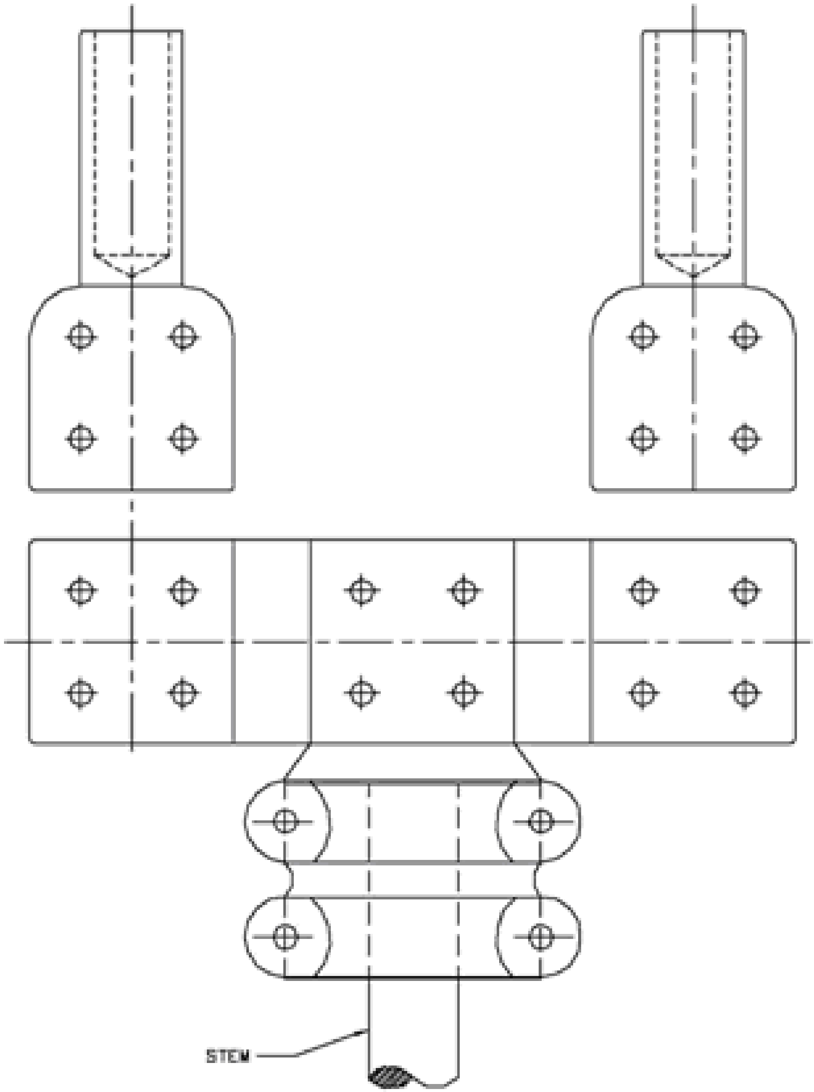


BIMETALLIC TERMINAL CONNECTOR

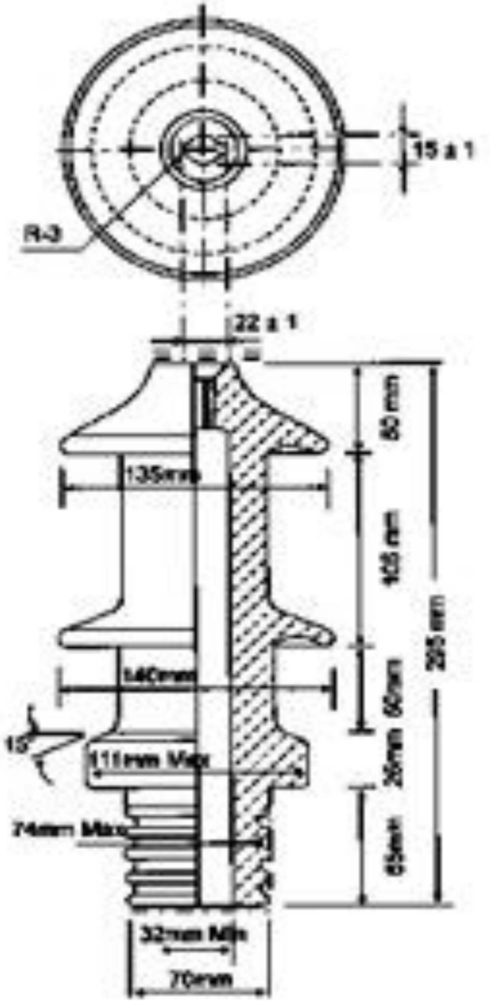
Bushings

3 different types

- Solid
- Oil filled
- Condenser

Condenser Bushings

- Synthetic Resin Bonded Paper Condenser
- Oil impregnated paper condenser
- Cast resin



HC - B 1201

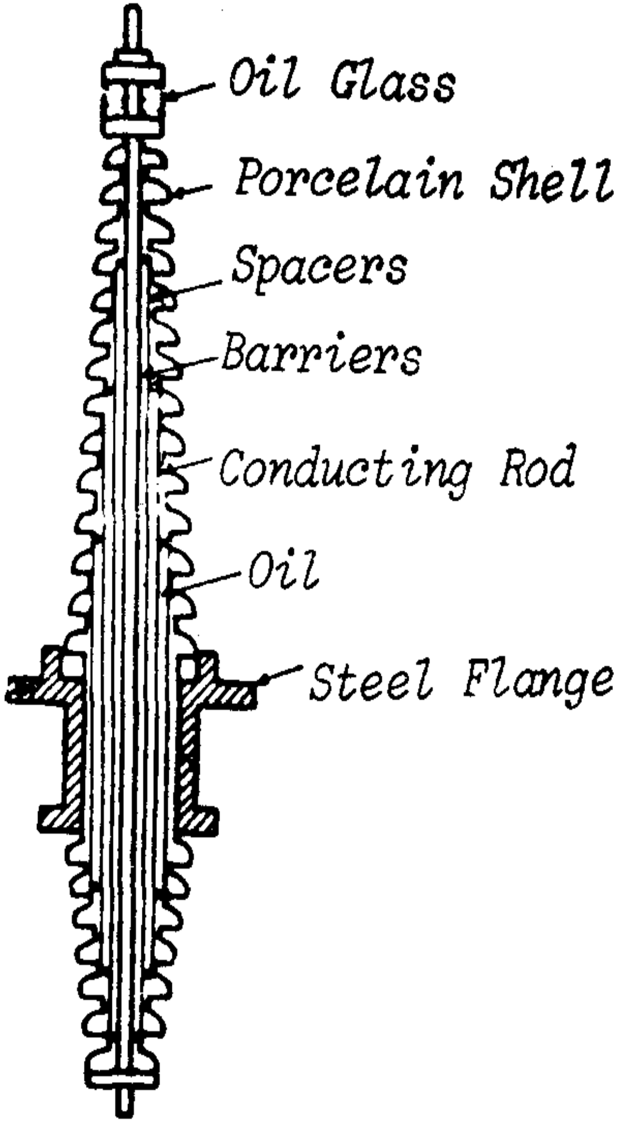


FIG: BUSHING ASSEMBLY

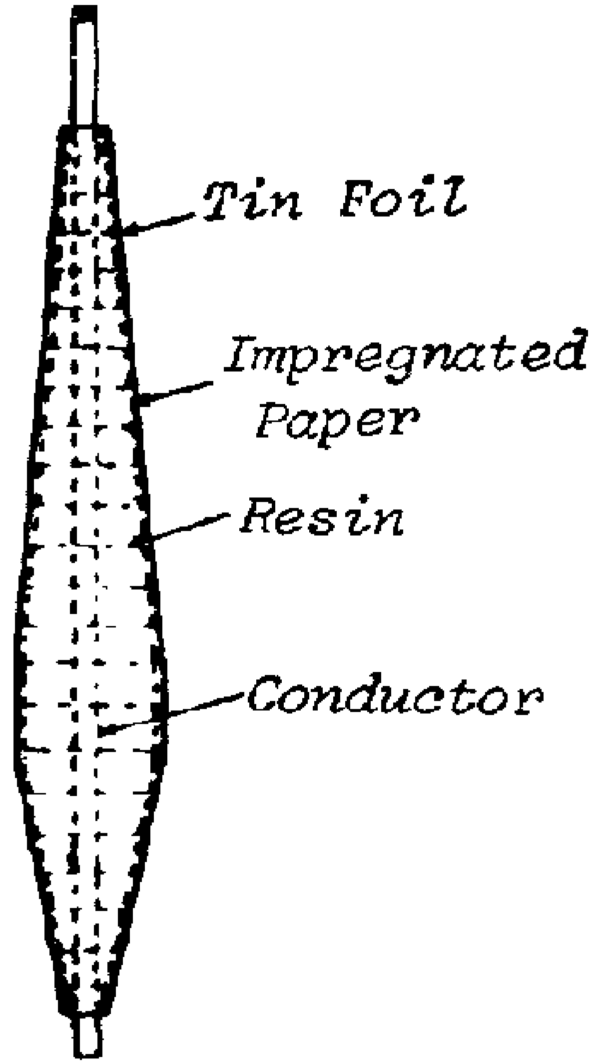
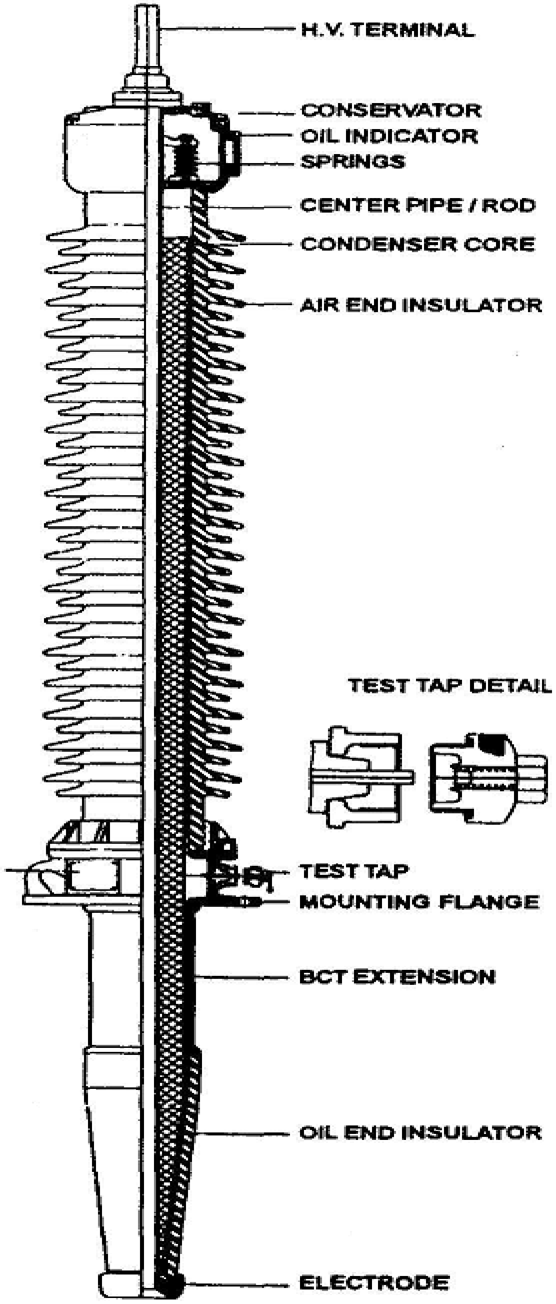


FIG: BUSHING CORE


H.V. TERMINAL
CONSERVATOR
OIL INDICATOR
SPRINGS
CENTER PIPE / ROD
CONDENSER CORE
AIR END INSULATOR
TEST TAP DETAIL
TEST TAP
MOUNTING FLANGE
BCT EXTENSION
OIL END INSULATOR
ELECTRODE

MARSHALLING BOX

Pressure relief device

- If a PRV does not operate properly and relieve pressure with in few milliseconds, the tank may burst
- During repainting, never paint PRV

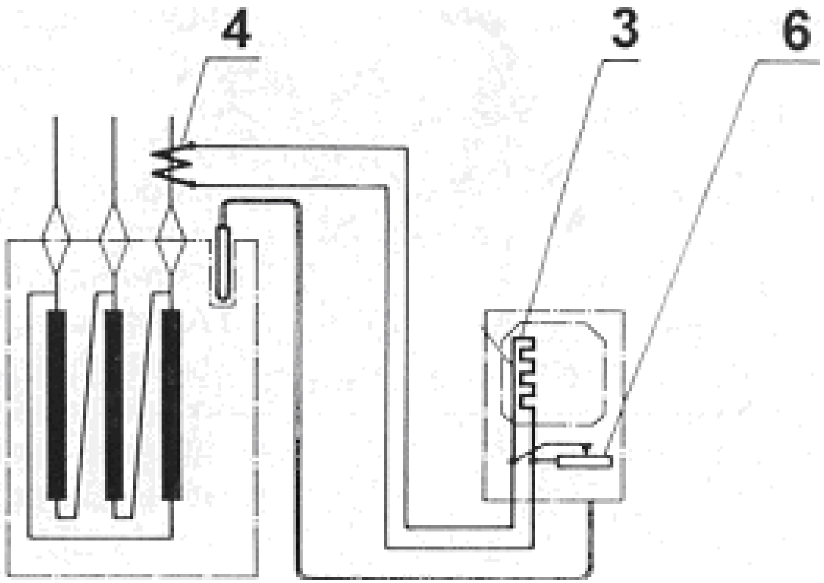
PRV

PRV

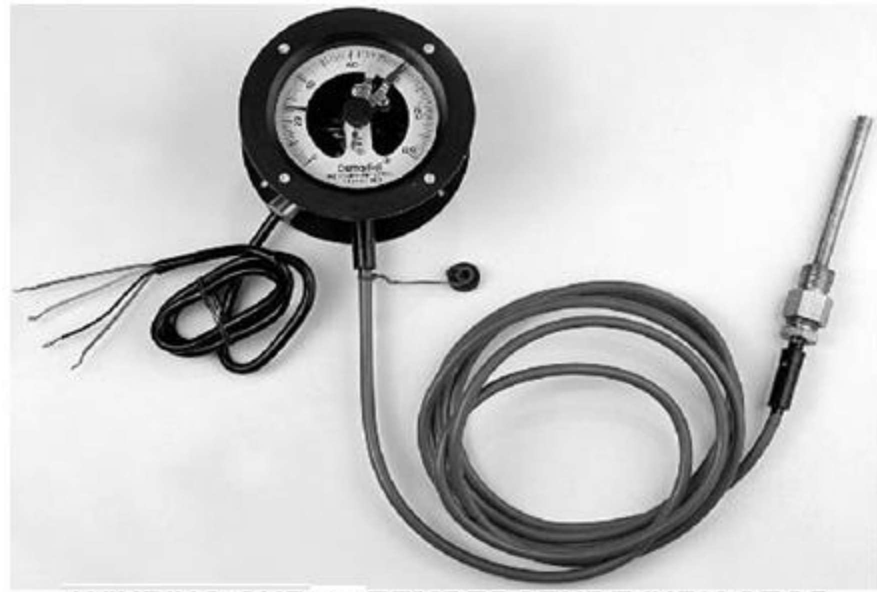
PRV

Oil Temperature Indicator

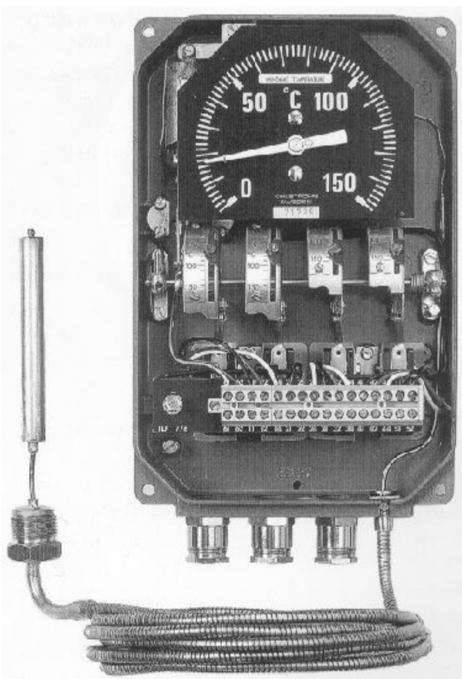
Winding Temperature Indicator

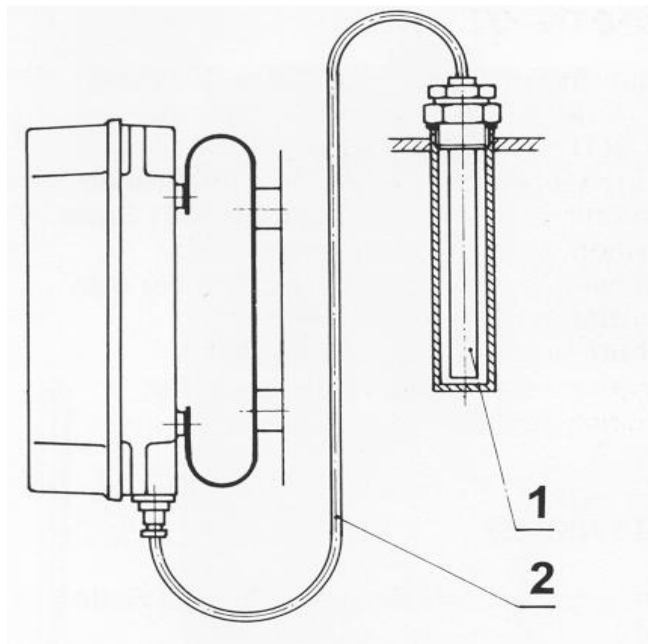


Winding Temperature indicator



WINDING AND OIL TEMPERATURE INDICATOR

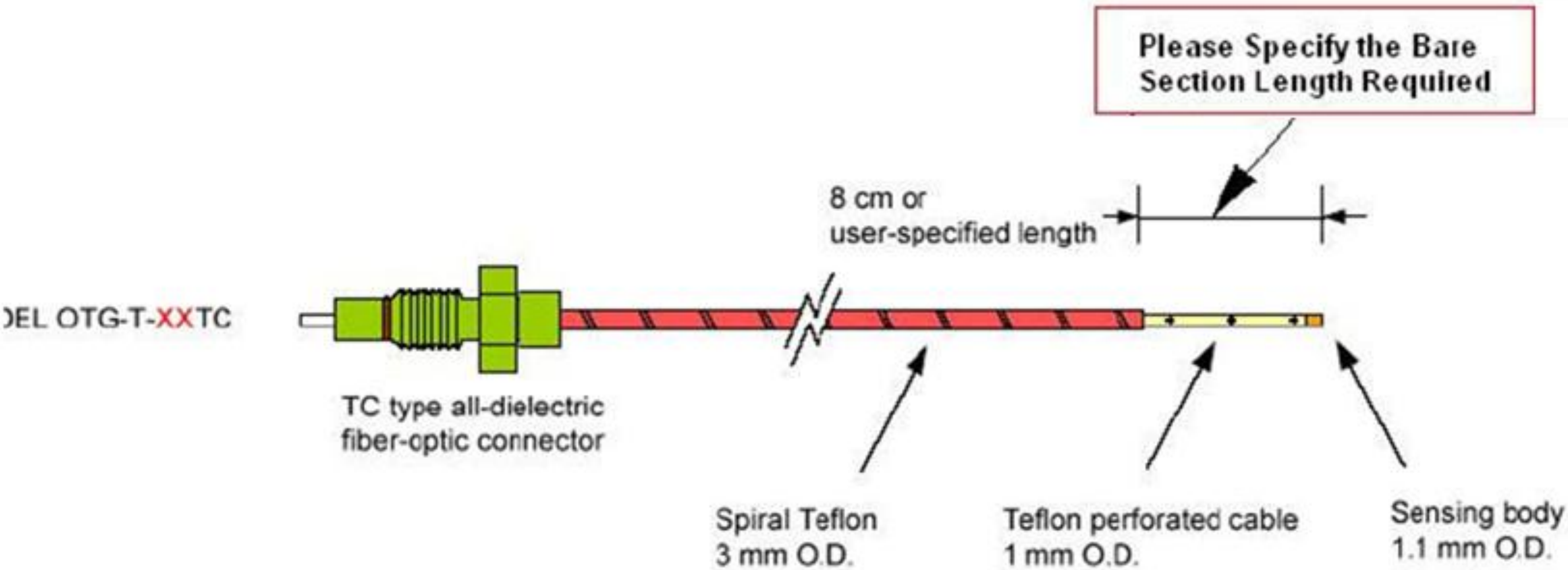




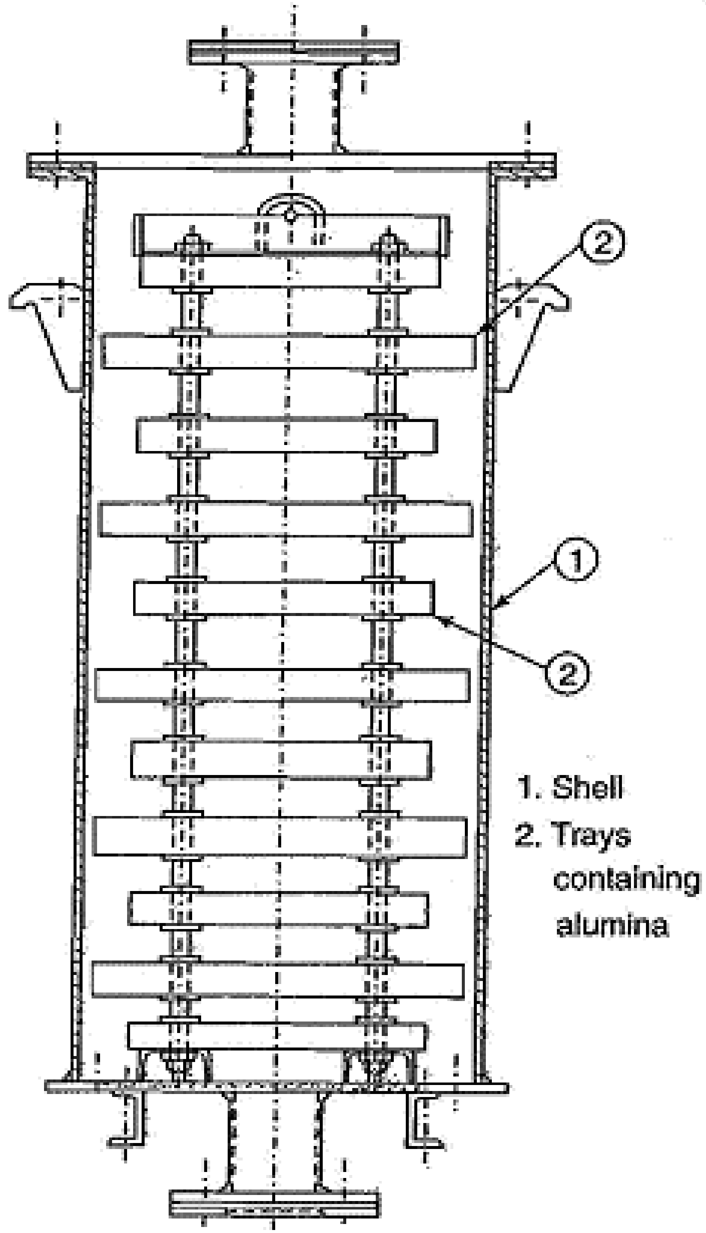
DIFFERENT MODELS OF WTI

1) SENSOR:

GAS-BASED FIBER OPTIC TEMPERATURE SENSOR FOR POWER TRANSFORMER APPLICAIONS



XX = Sensor Size 1) 200 for 200/230 microns optical fiber
2) 62 for 62.5/125 microns optical fiber



THERMOSIPHON FILTER

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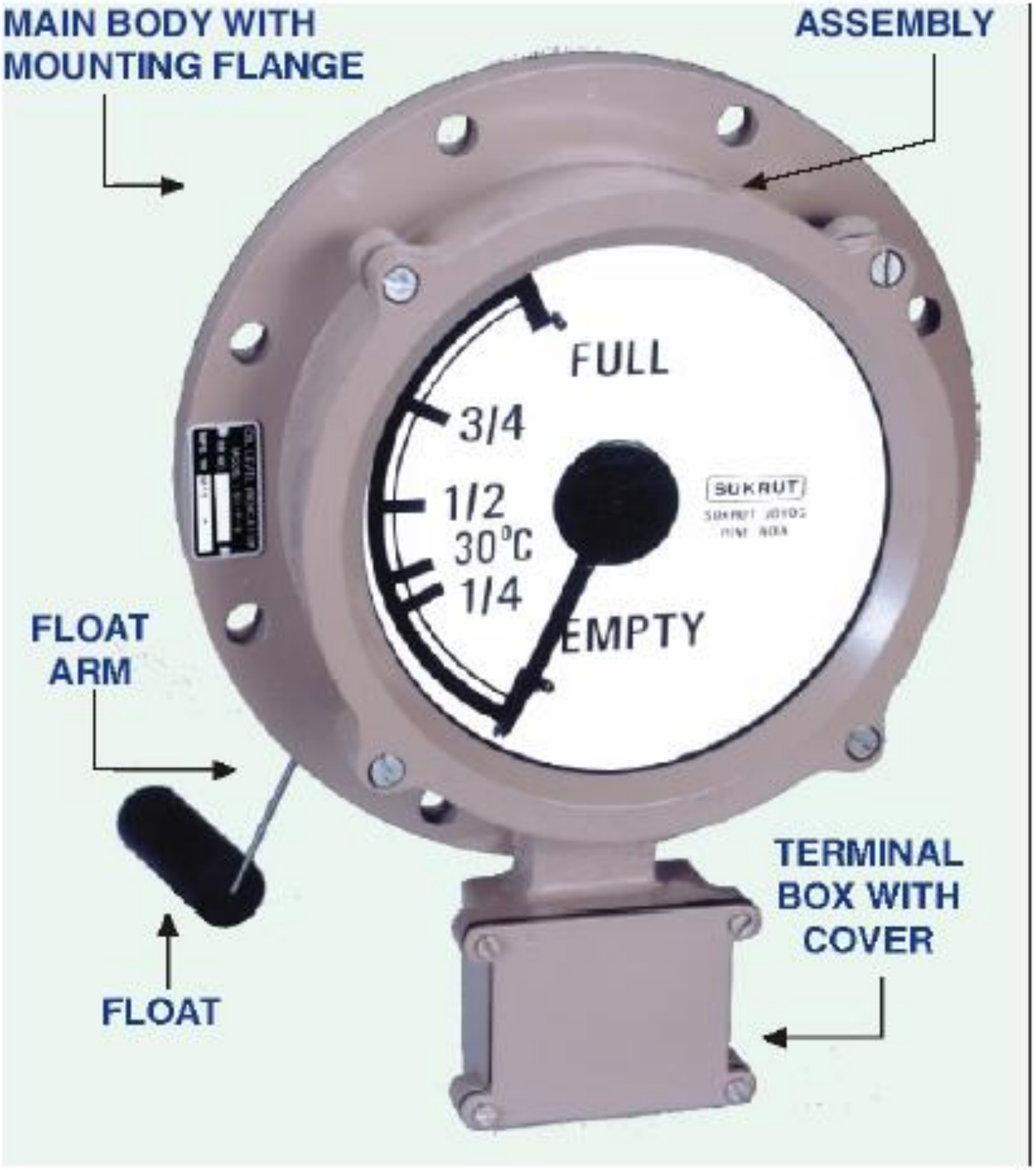
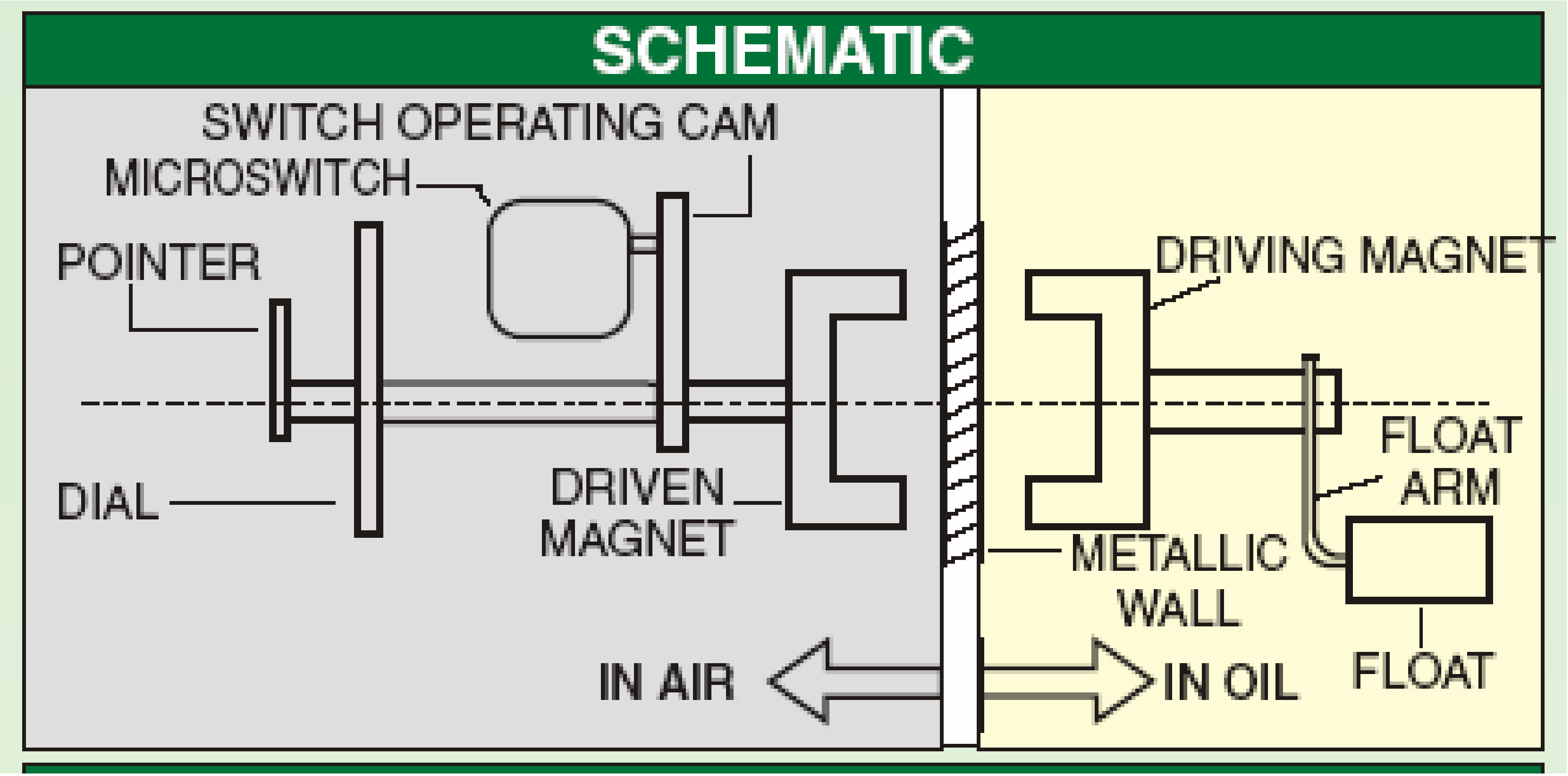
Magnetic oil level gauge




SCHEMATIC
SWITCH OPERATING CAM
MICROSWITCH
POINTER
DRIVING MAGNET
FLOAT
ARM
DIAL
DRIVEN
MAGNET
METALLIC
WALL
IN AIR
IN OIL
FLOAT

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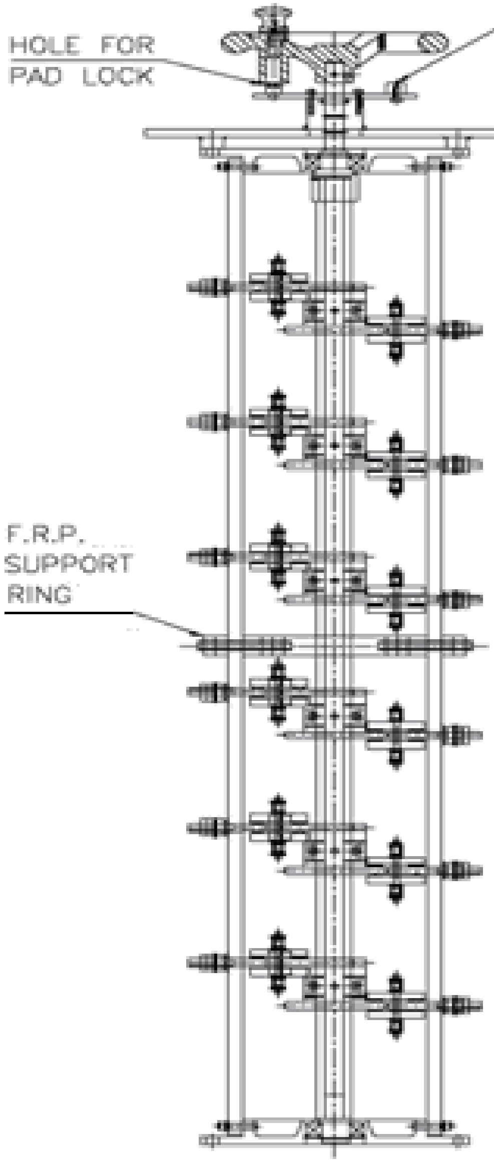
OFF - CIRCUIT TAP CHANGER



OFF CIRCUIT TAP SWITCH

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OLTC

Diverter switch

Tap selector

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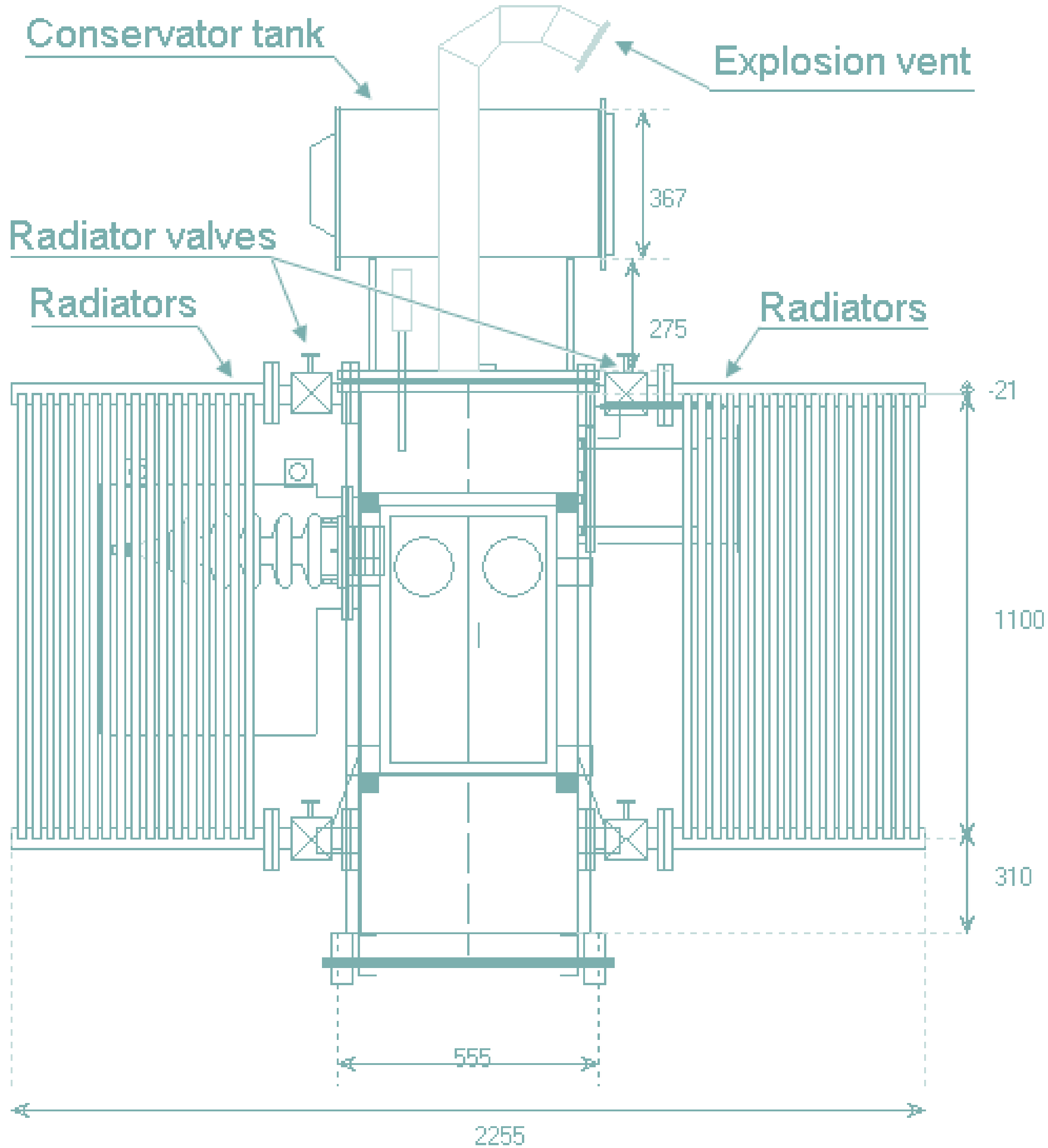
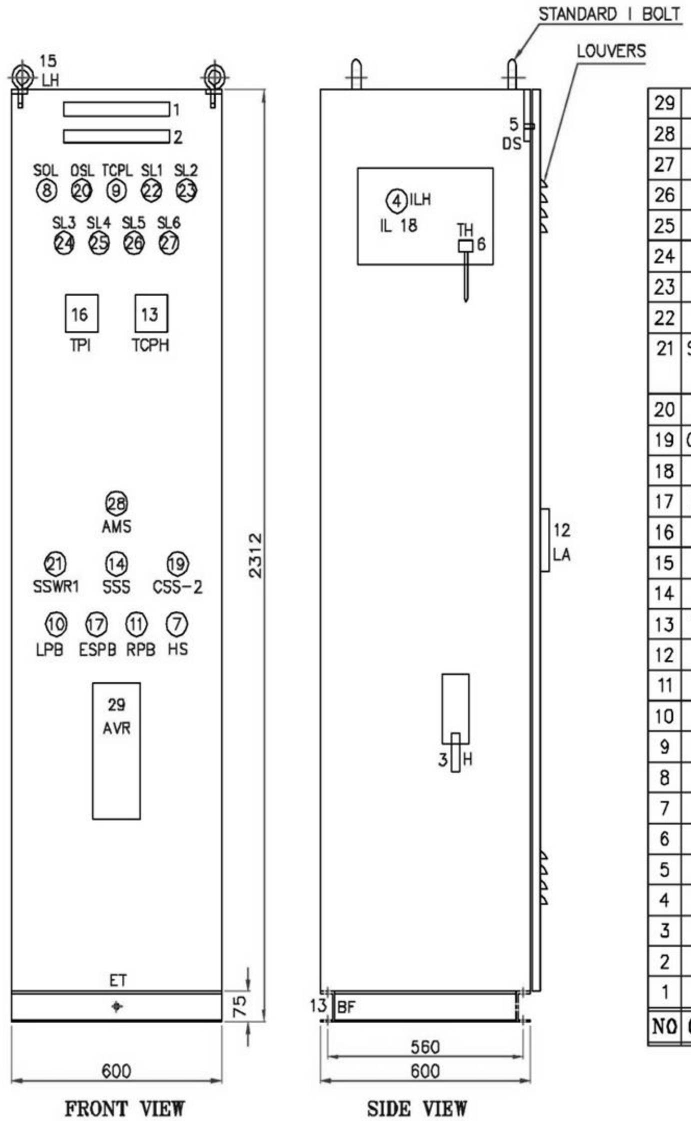


Conservator Tank, Radiator and Explosion Vent



RTCC PANEL WITH AVR

NO	CODE	DESCRIPTION	QTY
29	AVR	AUTOMATIC VOLTAGE REGULATOR (FX 1000 OR EQUIV.)	1
28	AMS	AUTO-MANUAL SELECTOR SWITCH FOR AVR	1
27	SL6	STAND BY FAN-6 "ON" IN GROUP "B"	1
26	SL5	FAN-5 "ON" IN GROUP "B"	1
25	SL4	FAN-4 "ON" IN GROUP "B"	1
24	SL3	STAND BY FAN-3 "ON" IN GROUP "A"	1
23	SL2	FAN-2 "ON" IN GROUP "A"	1
22	SL1	FAN-1 "ON" IN GROUP "A"	1
21	SSWR1	CONTROL SELECTOR SWITCH FOR AUTO/MANUAL 1 POLE,2 WAY WITHOUT OFF FOR FAN	1
20	OSL	OLTC OUT OF STEP LAMP -RED	1
19	CSS-2	CONTROL SUPPLY ON/OFF SWITCH, 4 POLE	1
18	IL	ILLUMINATION LAMP	1
17	ESPB	EMERGENCY STOP PUSH BUTTON (STAY PUT TYPE)	1
16	TPI	TAP POSITION INDICATOR	1
15	LH	LIFTING HOOK	2
14	SSS	SEQUENCE SELECTOR SWITCH[IND/OFF/MASTER/FOLLOWER]	1
13	TCPH	TAP CHANGE IN PROGRESS HOOTER	1
12	LA	LOCKING ARRANGMENT	1
11	RPB	"RAISE" PUSH BUTTON	1
10	LPB	"LOWER" PUSH BUTTON	1
9	TCPL	TAP CHANGER IN PROGRESS LAMP-AMBER	1
8	SOL	OLTC SUPPLY ON LAMP – WHITE	1
7	HS	HEATER SWITCH 'ON-OFF'	1
6	TH	THERMOSTAT	
5	DS	DOOR SWITCH	1
4	ILH	ILLUMINATION LAMP HOLDER	1
3	H	HEATER	1
2		NAME PLATE FOR RTCC	1
1		NAME PLATE FOR T & R	1

THANQ