Distribution Transformers

Week 10-11
Transformers classifications:

**By field of usage:**
- Power transformer for transmission network
- Distribution transformer for distribution networks
- Power supply
- Isolation
- Rectifier
- Arc furnace

The size of any of those transformers ranges from for example 10 m (height, width..), 10 tons as in the power transformer to size in cm and weight that does not exceed 10 grams as in power supply (used in chargers)

2. **Number of phases**
   - Single phase
   - Three phase
Transformers classifications:

3. **Cooling:**
   - Self air cooled (dry type)
   - Air blast cooled (dry type)
   - Liquid immersed, dry cooled
   - Oil immersed, combination self cooled and air blast
   - Oil immersed, water cooled
   - Oil immersed, forced air cooled
   - Oil immersed, combination self cooled and water cooled

4. **According to transformation:**
   - Step up
   - Step down

5. **According to frequency:**
   - Low frequency (power and distribution transformer)
   - Very high, high frequency transformers (communication and power electronic devices)
   - Intermittent frequency transformer (communication)
# Power Transformer Vs Distribution Transformer

<table>
<thead>
<tr>
<th>Point</th>
<th>Power Transformer</th>
<th>Distribution Transformer</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Uses</strong></td>
<td>Used in generating stations as a step up transformer, and in transmission substations as a step down (at 500 kV, 132 kV, 66 kV, 33 kV)</td>
<td>Used for low voltage distribution as less than 33 kV in industrial purposes and 380V/220V in domestic purposes and always as step down</td>
</tr>
<tr>
<td><strong>Size</strong></td>
<td>Big and large</td>
<td>Smaller size</td>
</tr>
<tr>
<td><strong>Full load operation</strong></td>
<td>Near full load operation (100% full load)</td>
<td>Operates at 60-70% full load all day</td>
</tr>
<tr>
<td><strong>Efficiency</strong></td>
<td>• High (98-99%)&lt;br&gt;• Efficiency= output power (kW)/ input power (kW)</td>
<td>• Low (50-70%)&lt;br&gt;• All day Efficiency= output power (kWhr)/ input power (kWhr) in 24 hrs</td>
</tr>
<tr>
<td><strong>Tap changer</strong></td>
<td>• On-load tap changer&lt;br&gt;• Points: 17 points and more&lt;br&gt;• Operation: automatic using separate control&lt;br&gt;• Media surrounding the taps: oil filled cylinder for arc extinguish placed in parallel to the windings&lt;br&gt;• Arc extinguish occurring during tap change: Oil</td>
<td>• Off-load tap changer&lt;br&gt;• Points: 3-5 points&lt;br&gt;• Operation: Manual after source (voltage) is disconnected from transformer&lt;br&gt;• Media surrounding the taps: transformer oil&lt;br&gt;• Arc extinguish occurring during tap change: transformer must be disconnected from any voltage source</td>
</tr>
<tr>
<td><strong>Protection</strong></td>
<td>• Buchholz replay (جهاز الوقاية الغازية)&lt;br&gt;• Explosion vent pressure relief (فتحة الانفجار)&lt;br&gt;• Temperature indicators&lt;br&gt;• Oil level gauges&lt;br&gt;• Lighting arrestors&lt;br&gt;• Differential protection, over current, over flux, restricted earth fault</td>
<td>• HRC fuse&lt;br&gt;• Over current, Buchholz relay and restricted earth fault protection for large transformers larger than 500 kVA</td>
</tr>
</tbody>
</table>
On load versus Off load tap changer

<p>| | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Off load tap changer</td>
<td></td>
<td></td>
</tr>
<tr>
<td>+ 5.0% tap</td>
<td>13,860/480 V</td>
<td></td>
</tr>
<tr>
<td>+ 2.5% tap</td>
<td>13,530/480 V</td>
<td></td>
</tr>
<tr>
<td>Nominal rating</td>
<td>13,200/480 V</td>
<td></td>
</tr>
<tr>
<td>-2.5% tap</td>
<td>12,870/480 V</td>
<td></td>
</tr>
</tbody>
</table>

OFF-LOAD TAPS

<table>
<thead>
<tr>
<th>HV</th>
<th>Switch Position</th>
</tr>
</thead>
<tbody>
<tr>
<td>105</td>
<td>1</td>
</tr>
<tr>
<td>102.5</td>
<td>2</td>
</tr>
<tr>
<td>100</td>
<td>3</td>
</tr>
<tr>
<td>97.5</td>
<td>4</td>
</tr>
<tr>
<td>95</td>
<td>5</td>
</tr>
</tbody>
</table>

ON LOAD TAP CHANGER
**Distribution Transformer Locations**

- **Overhead**
  
  In overhead distribution systems (mostly in rural or suburban areas) small transformers, either single-phase or three phase, may be mounted directly on the overhead line poles whereas larger transformers are mounted on special frames supported by a two-pole structure.

- **Underground**
  
  Distribution transformers can be installed in ventilated underground or above-ground vaults, away from public access. Depending on the type of distribution system and the vault’s exposure to standing water, the transformer may be referred to as **vault-type, network, or submersible**. It is dry type based.
Distribution Transformer Locations

- **Pad mounts**

  Outdoor transformers utilized as part of an underground distribution system, have three separate enclosed compartments for high voltage equipment, for low voltage equipment and for the transformer itself and are known as packaged transformer substations.

- **Interior installations**

  Building codes generally prohibit the installation of a distribution transformer containing mineral oil inside or immediately adjacent to an occupied building. The options available include use of a dry-type transformer and the replacement of mineral oil with a less flammable coolant.
Transformer Connections

Different transformer connections
(a) - △  (b) △ - (c) △ - △ (d) -
Transformer Connections

Star-Star:

- Least number of windings compared to any other connection and least insulation as the winding voltage is less by a factor or $\sqrt{3}$ compared to line voltage. Voltage stresses on windings are limited.
- Requires large cross section (thus has high impedance) for the windings compared to other connections as line and phase currents are the same. Large cross section offers the connection good mechanical stability.
- Most economical connection for high voltage and low current transformers.
- Four wire system and offers the availability of a neutral point for earthing.
- Third harmonic component is not cancelled out.
- Unbalancing causes the instability of the neutral point.
- Used in small power transformers, interconnecting two delta systems, large transmission transformers.
- In case of a faulted phase, the other two lines work normally.
Transformer Connections

Delta-Delta

- Requires more windings and large insulation for windings as the line voltage is the same as phase voltage thus voltage stresses are high
- Economical in transformers with high current capabilities and low voltages
- Least connection in terms of mechanical stability due to small cross section of cables and high number of windings
- If one of the windings (or one of the transformers in case we use a bank of transformer) is disconnected, the other two remain in service thus producing almost 58% of the actual nominal apparent power.
- Third harmonic is eliminated but lacks the availability of neutral point thus requires high insulation due to the high voltage.
- No neutral access and thus requires special arrangement for grounding the transformer such as a zigzag transformer
- Not highly used but can be used to supply unbalanced loads
3. **Star-Delta**

- Delta cancels third harmonic
- Star provides way for grounding the transformer
- Delta ensures the balance of neutral point of the star
- Any fault present on any of the sides requires total disconnection of transformer
- **Not preferred to be used as a step up** function as delta windings are weak in terms of mechanical stability
- Very well suited in voltage **step down** function and in transmission systems
Transformer Connections

**Delta-star**

- Delta cancels third harmonic
- Star provides way for grounding the transformer
- Delta ensures the balance of neutral point of the star
- Any fault present on any of the sides requires total disconnection of transformer
- **Not preferred to be used as a step down function** as delta windings are weak in terms of mechanical stability
- Very well suited in voltage *step up* function and in transmission systems
- Used in distribution transformers for supplying loads that requires 4 wire system, balanced or unbalanced.
Transformer Connections

Zig Zag (delta zigzag) arrangement

- Also known as “interconnected star”
- Each winding is made of two windings
- Economical compared to delta star arrangement that requires high insulation and large number of windings
- Possible to get neutral point
- Mechanical stability at zigzag side better than delta side
- Interconnection of phases in zigzag winding effects a reduction of third harmonic voltages and at the same time permits unbalanced loading.
- Due to zigzag connection, third harmonic voltages are reduced. It also allows unbalanced loading. The zigzag connection is employed for LV winding.
- The Zig Zag winding reduces voltage unbalance in systems where the load is not equally distributed between phases, and permits neutral current loading. It is therefore often used for earthing transformers.

Application: creation of a missing neutral connection from an ungrounded 3-phase system to permit the grounding of that neutral to an earth reference point and also harmonic mitigation.
Transformer Vector Groups

- **IEC** gives a method for transformer vector group representation based on its windings connection using the following notation system:

  - **Capital letters represents the primary winding connection:**
    - D for delta
    - Y for star
    - Z zig-zag connection
    - III for separate (unconnected) windings

  - **Small letters represents the secondary winding connection:**
    - d for delta
    - y for star
    - z for zig-zag connection
    - iii for separate (unconnected) windings

  - A number following the above two letters indicates the angle (as multiples of 30°) by which the secondary voltage lags the primary voltage.

  - **For example** Yd11 represents a transformer with star connected primary and delta connected secondary with the secondary voltage lagging the primary voltage by $11 \times 30^\circ = 330^\circ$.
## Different transformer vector groups

<table>
<thead>
<tr>
<th>Group</th>
<th>Connection</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td><img src="image1.png" alt="Diagram" /></td>
</tr>
<tr>
<td>1</td>
<td><img src="image2.png" alt="Diagram" /></td>
</tr>
<tr>
<td>5</td>
<td><img src="image3.png" alt="Diagram" /></td>
</tr>
<tr>
<td>6</td>
<td><img src="image4.png" alt="Diagram" /></td>
</tr>
</tbody>
</table>

The table is formed based on IEC 60076 and the idea that the winding directions of the HV and LV windings are the same.
What is the function of the oil in the transformer:

**Cooling:** Internal temperature rise in transformer if left could cause serious damage on transformer. Oil easily penetrates between windings and heat is transferred to oil. Heat is then being rejected out of the oil either through fans or radiators or through the contact between the transformer body and the oil itself.

- **Insulation:** insulation between windings themselves and between the windings and the core

- **Protection:** Covers all metallic parts and prevents oxidation process which affects conductivity and prevents any other chemical reactions that causes corrosion.

- **Fault diagnosis:** Used to detect many internal faults in the transformer. Fault cause changes in the chemistry of the oil due to the large energy accompanied by faults. Oil is analyses and results are used to determine the type of internal fault inside of the transformer.
# Cooling Classes of Transformers

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Medium</th>
<th>نوع</th>
</tr>
</thead>
<tbody>
<tr>
<td>O</td>
<td>Mineral oil (natural oil)</td>
<td>زيت معدني</td>
</tr>
<tr>
<td>L</td>
<td>Artificial (industrial) oil</td>
<td>سائل صناعي عازل</td>
</tr>
<tr>
<td></td>
<td>Ex: Askael, Silicone Fluid</td>
<td>مائع السيليكون</td>
</tr>
<tr>
<td>G</td>
<td>Gas</td>
<td>غاز</td>
</tr>
<tr>
<td>W</td>
<td>Water</td>
<td>ماء</td>
</tr>
<tr>
<td>A</td>
<td>Air</td>
<td>هواء</td>
</tr>
<tr>
<td>S</td>
<td>Solid insulator</td>
<td>عازل صلد</td>
</tr>
</tbody>
</table>

- The mostly common used are air and oil. Oil used with outdoor transformers.

- **Air is used in dry type transformers, and has disadvantages:**
  - Loading of transformers for short time
  - Windings are subject to dust and dirt and could lead to insulation weakening
  - Windings are bigger for easier air penetration
Dry Type Transformer Advantages

- Cheapest type of fire proof transformers
- Can be safely installed inside buildings without any fire protection scheme and could be installed outside buildings
- Doesn't need maintenance procedure or periodical checkups like oil type transformers. Cleaning of air paths and transformer core is easily done
- Doesn't require arrangements that are needed with oil type transformers such as discharge path, measuring devices and the most we can do is install a temperature thermometer in contact with windings to adjust winding temperature
- Light in weight and is easily installed
- High efficiency, good voltage regulation
- Can cope with loading
Cooling Classes of Transformers

According to the IEC the identification of the method used for the cooling of transformers is as follows:

<table>
<thead>
<tr>
<th>الحرف الأول</th>
<th>الحرف الثاني</th>
<th>الحرف الثالث</th>
<th>الحرف الرابع</th>
</tr>
</thead>
<tbody>
<tr>
<td>نوع وسط التبريد الملامس مباشرة للملفقات (داخلي)</td>
<td>نوع التقليب</td>
<td>نوع وسط التبريد الملامس لنظام التبريد الخارجي</td>
<td>نوع التقليب</td>
</tr>
</tbody>
</table>

**Example**

<table>
<thead>
<tr>
<th>O</th>
<th>N</th>
<th>A</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>وسط التبريد الداخلي (زيت)</td>
<td>نوع التقليب (طبيعي)</td>
<td>وسط التبريد الخارجي (هواء)</td>
<td>نوع التقليب الخارجي (طبيعي)</td>
</tr>
</tbody>
</table>

ONAN

ONAF
# Cooling Classes of Transformers

**Natural circulation (N):** means oil is cooled naturally when hot oil moves to the top and cold oil moves to the bottom of the tank.

**Forced circulation (F):** cooling in radiator increases oil viscosity, thus to increase cooling efficiency through use of fans which operates using thermostats.

<table>
<thead>
<tr>
<th>Cooling class (IEC)</th>
<th>Description</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>ONAN</td>
<td>Oil Natural Air Natural</td>
<td>natural convectional flow of hot oil is utilized for cooling in radiator</td>
</tr>
<tr>
<td>ONAF</td>
<td>Oil Natural Air Forced</td>
<td>applying forced air flow on the dissipating surface. Fans blowing air on cooling surface is employed. Forced air takes away the heat from the surface of radiator and provides better cooling than natural air</td>
</tr>
<tr>
<td>OFAF</td>
<td>Oil forced air natural</td>
<td>heat dissipation is accelerated by using forced air on the dissipating surface but circulation of the hot oil in transformer tank is forced to circulate within the closed loop of transformer tank by means of oil pumps.</td>
</tr>
<tr>
<td>ODAF</td>
<td>Oil directed Air Forced</td>
<td>Oil circulation is directed for more heat dissipation</td>
</tr>
<tr>
<td>ODWF</td>
<td>Oil directed water forced</td>
<td>hot oil is cooled in cooler by means of forced water instead of air</td>
</tr>
<tr>
<td>AN</td>
<td>Air natural</td>
<td>Used with dry type transformer</td>
</tr>
<tr>
<td>AF</td>
<td>Air forced</td>
<td>Used with dry type transformer</td>
</tr>
</tbody>
</table>
Cooling Classes of Transformers

ODAF

OFAF
II- For dry-type transformers also four letters are used to designate the manner of cooling:

- **First letter**: Internal cooling medium in contact with the windings,
  - A Air
  - G Gas

- **Second letter**: Circulation mechanism for internal cooling medium,
  - N Natural convection
  - F Forced cooling

- **Third letter**: External cooling medium,
  - A Air
  - G Gas

- **Fourth letter**: Circulation mechanism for external cooling medium,
  - N Natural convection
  - F Forced cooling
Distribution Transformer Main Parts

- MAIN TANK
- RADIATORS
- BREATHER UNIT
- CONSERVATOR
- PRESSURE RELIEF SYSTEM
- OIL LEVEL INDICATOR
- TEMPERATURE DIAL
- TAP CHANGER
- HV/LV BUSHINGS
- OIL FILLING PLUG
- DRAIN PLUG
- CABLE BOX
Distribution Transformer Main Parts

1- **Main oil Tank**: windings are placed and soaked in oil

2- **Expansion oil Tank (conservator) وعاء تمدد الزيت**: Installed above the main oil tank on the outer transformer frame and is connected to the main tank through a metallic tube. Oil can freely contract and expand during loading and thus the temperature of the oil increases and decreases. Loading can increase expansion up to 8%. The Tank compensates any loss in oil that may occur in the main tank.

3- **Bucchloz Relay**: Placed when a conservator tank is used, as it indicated faults and errors such as oil loss when oil level goes low, improper oil flow between the oil tank and the transformer. Moreover, it shows gas emission inside transformer due to any unusual operation (excessive loading or short circuit) and can issue a control signal which can be used to disconnect the transformer. It is equipped with a release valve in case oil exceeded its level.
3- **Buchloz Relay:** The gas color actually indicated the type of fault in the transformer:
- White fumes: insulation paper failure
- Yellow fumes: insulation fiber burn
- Black fumes: Oil decomposition and burn out

4- **Breather Unit:** As mentioned earlier, any decrease in oil is being compensated by the conservator tank which leads to decrease in oil in the conservator tank itself and thus the air gap widens in the tank and air is pulled from outside through what is known as “dehydrated breathing unit” which contains “silica gel” that absorbs any moisture present in the oil. Silica changes its color from blue to pink if its unable to absorb moisture.
5- **Oil indicator:** Indicates level of oil in the conservator unit. Decrease in oil can cause flashover if it is not corrected.

6- **Temperature detector and contacts:** To monitor oil temperature and if temperature exceeded a certain limit, transformer is disconnected from service.

7- **Pressure relief device and explosion vent:** reduces pressure inside the transformer through external pressure release to avoid explosion of transformer.

8- **Thermal relay:** used as indicator of winding temperature and also can be used to activate fans or alarms (used with large transformers).
9- **Radiator:** Added to increase cooling efficiency of the transformer and is equipped with a pump which continuously pumps oil in the radiator. In this case, cooling is assumed to be “natural air” as it depends on natural circulation and air cooling the oil. Sometimes fans are added to the radiator. Radiator action is called “forced action” as it employs fans and radiator pump.

10- **Bushing:** responsible for connecting the internal windings of the transformer with the external electrical network. It isolates the internal windings from the transformer body. Bushings are fixed using flanges to avoid any humidity, dirt and dust from reaching the points of contact.
According to the Egyptian code, transformer is sized based on the maximum connected load and according to the following:

\[ S_{\text{transformer}}(kVA) = 1.25 \times S_{\text{max}}(kVA) \]

This means that the transformer is loaded to 80% of its full load.

Temperature rise permissible limits in distribution transformers (when loaded) is based on its nominal rating (for duration not less than 6 hrs) according to:

1. Oil temperature must not exceed 45 degree C in the expansion tank.
2. Average winding temp. rise is 60 degree c (measured by measuring winding resistance).
3. Expansion tank oil temp. must be contained so as not to affect the external enclosure.
K factor in Transformers

K-factor is a **weighting of the harmonic load currents** according to their effects on transformer heating, as derived from ANSI/IEEE C57.110. A K-factor of 1.0 indicates a linear load (no harmonics). The higher the K-factor, the greater the harmonic heating effects.

- When a non-linear load is supplied from a transformer, it is sometimes necessary to de-rate the transformer capacity to avoid overheating and subsequent insulation failure.

- The reason for this is that the increased eddy currents caused by the harmonics increase transformer losses and thus generate additional heat. Also, the RMS load current could be much higher than the kVA rating of the load would indicate. Hence, a transformer rated for the expected load will have insufficient capacity.
K factor in Transformers

The K factor is derived from a mathematical formula, which states that the eddy current losses in a transformer will be increased in direct proportion to the sum of the percentage current at a given harmonic level multiplied by the square of the harmonic order.

- K-factor transformers are preferred because they have additional thermal capacity of known limits,
- Transformers come in basic K-factors such as 4, 9, 13, 20, 30, 40, and 50.
- A k-factor = 4 means that the percentage of non-linear loads can reach up to 50% from rated transformer load. A k-factor of 13 means 100% of loads are non-linear.