**Single phase Auto-transformer:**

![Diagram of Single phase Auto-transformer](image)

The input to auto-transformer is given across CB and the output of the auto-transformer is taken across CE. If the input voltage to auto-transformer is given across CA, the maximum output voltage across CE is equal to input voltage. However, if we give the input voltage across CB, the maximum output voltage can be made greater than the input voltage.

**Wattmeter:**

![Diagram of Wattmeter](image)

In wattmeter ML is called current coil and CV is called pressure coil or pressure coil. While connecting wattmeter the terminals M and C should be connected. Instead if the terminals L
and C are connected then the current through current coil (ML) will be \((I_L + I_V)\). This leads to the wrong measurement of power consumed by load \(Z_L\). Hence, the wattmeter should always be connected as shown in the figure.
**Experiment no. 1**

**PARALLEL OPERATION OF TWO SINGLE-PHASE TRANSFORMERS**

**Introduction:**

When the load outgrows the capacity of an existing transformer, it may be economical to install another one in parallel with it rather than replacing it with a single larger unit. Also, sometimes in a new installation, two units in parallel, though more expensive, may be preferred over a single unit for the reasons of reliability- half the load can be supplied with one unit out. Further, the cost of maintaining a spare is less with two units in parallel.

The satisfactory and successful operation of transformers connected in parallel on both sides requires that they fulfill the following conditions:

1. The transformers must be connected properly as far as their polarities are concerned so that the net voltage around the local loop is zero. A wrong polarity connection results in a dead short circuit.
2. The secondary sides of the two-single phase transformers must have zero relative phase displacement.
3. The transformer must have the same voltage ratings to avoid no-load circulating current. Since the leakage impedance is low, even a small voltage difference can give rise to considerable no-load circulating current and extra $I^2R$ loss.

**THEORY:**

Let the rated voltages of the primary side of the two single phase transformers (transformer A and transformer B) used in parallel operation be $V_a$ and $V_b$ and let their turns ratio be $N_a$: 1 and $N_b$: 1. As the two transformers are connected in parallel, by Kirchhoff’s laws the voltage equations of the transformers can be written as,

\[
V_a = I_a Z_a + I_L Z_L = I_a Z_a + (I_a + I_b) Z_L \tag{1}
\]

\[
V_b = I_b Z_b + I_L Z_L = I_b Z_b + (I_a + I_b) Z_L \tag{2}
\]

Therefore,

\[
V_a - V_b = I_a Z_a - I_b Z_b \tag{3}
\]

Where, $Z_a$ and $Z_b$ are the impedances of the transformers, $Z_L$ is the load impedance and $I_L$ is the load current. All the quantities are referred to the primary side.

Under no-load $I_L=0$, so that the circulating current between the two transformers is given by,

\[
I_a = -I_b \frac{V_a - V_b}{Z_a + Z_b} \tag{4}
\]
Under short-circuit, 
\[ I_a = \frac{V_a}{Z_a}, \quad I_b = \frac{V_b}{Z_b} \]  
\[(5)\]

On loading, 
\[ I_a = \frac{(V_a - V_b) + I_b Z_b}{Z_a} \]  
\[(6)\]

Substituting for \( I_a \) in equation (2) we get
\[ I_b = \frac{V_a Z_a - (V_a - V_b) Z_L}{Z_a Z_b + Z_L (Z_a + Z_b)} \]  
\[(7)\]

Similarly,
\[ I_a = \frac{V_a Z_b + (V_a - V_b) Z_L}{Z_a Z_b + Z_L (Z_a + Z_b)} \]  
\[(8)\]

If the voltage ratings of the two transformers are same, i.e., \( V_a = V_b \), we have from (7) and (8),
\[ \frac{I_a}{I_b} = \frac{Z_b}{Z_a} \]  
\[(9)\]

Or,
\[ \frac{I_a Z_a}{V_a} = \frac{I_b Z_b}{V_a} \]

i.e.,
\[ Z_a (pu) = Z_b (pu) \]  
\[(10)\]

From equation (9) we can write,
\[ I_a = \frac{Z_2}{(Z_a + Z_b)} I \]
\[ I_b = \frac{Z_a}{(Z_a + Z_b)} I \]
\[ I = I_a + I_b \]  
\[(11)\]

Since the voltage ratings are same, the kVA ratings of the transformers are,
\[ S_a = V_a I_a \times 10^{-3} \]
\[ S_b = V_b I_b \times 10^{-3} \]  
\[(12)\]

From (11) and (12)
\[ S_a = \frac{Z_b}{(Z_a + Z_b)} S \]
\[ S_b = \frac{Z_a}{(Z_a + Z_b)} S \]  
\[(13)\]

As the kVA distribution among the transformers depends on impedance ratios, the per unit values may be used but they must be adjusted to the same base kVA.

**Objectives:**

1. To determine and verify the polarity of the individual single-phase transformers.
2. To find the impedance of the single phase transformers by short circuit test.
3. To study parallel operation of (the above) two single phase transformers and observe the load sharing between them.

**Determination of Polarity of a Single Phase Transformer:**

1. Mark the primary winding terminals of one single phase terminals as \( A_1 \) and \( A_2 \). The choice of terminal for marking is arbitrary. Similarly mark secondary winding terminals as \( a_1 \) and \( a_2 \).
2. Connect the terminals of the two windings as shown in Fig. 1.
3. Also connect the primary winding terminals to an autotransformer through a double pole double throw (DPDT) switch (Fig. 1).
4. Choose appropriate value of the Fuse wire in the DPDT.
5. Make sure that the autotransformer is in the zero voltage position. Now switch on the power supply and throw on the DPST switch.
6. Gradually increase the autotransformer voltage (up to the rated primary voltage) and measure the voltage between terminals \( A_2 \) (primary) and \( a_2 \) (secondary) from voltmeter \( V \). Suppose the rated voltage ratio of the transformer is \( V_1:V_2 \). In case terminal \( A_1 \) and \( a_1 \) are of the same polarity, the reading of the voltmeter will be \( (V_1 - V_2) \), otherwise the reading of the voltmeter will be \( (V_1 + V_2) \). Similar polarity terminals can be marked with the same sign (+ or -).
7. Once done with the polarity determination, reduce the autotransformer voltage to ‘0’ and open the DPST switch. Turn off the power supply.
8. Determine the polarity of the other transformer following the same procedure.

![Fig. 1: Circuit connection for polarity test](image)

**Verification of the obtained polarity:**

1. Make the connection as shown in Figure 4 (A single floating voltmeter can serve as \( V_1, V_2 \) and \( V_3 \)).
2. Switch on the power supply to the autotransformer and follow the same procedure as before while gradually increasing the autotransformer output voltage keeping \( S_1 \) closed. Note→ keep all other switches open. The Wattmeter connections should be made as was explained earlier in the manual.
3. Observe the reading of V2. If it’s non-zero (i.e. anything other than a very small voltage difference) then the polarity connections for any one of the Transformer’s should be reversed.

4. In case polarity reversal is to be made switch off the system following the procedure mentioned above, and change the connections of any one transformer (i.e. the connections at the secondary end).

Parallel Operation of Two Single Phase Transformers:

1. Having done the polarity check next close the switch S2.

2. For the load choose a gang rheostat of appropriate power rating (If the transformers are perfectly matched or are near perfectly matched, as is the requirement for zero inter transformer circulation current, the power sharing will be in accordance with the respective power ratings of the two transformers).

3. In case there are two secondary windings and one is being used or the output voltage being tapped is a percentage of the maximum available then the KVA rating of the transformers during usage will be less than that given on Name Plate. If either of the previously mentioned conditions happens to be true, determine the correct KVA rating of usage. Based on it determine the maximum rated current that shall flow in the primary and the secondary.

4. Now increase the load in steps of 0.5 (the minimum step of the gang rheostat) till either A1 or A2 reads the maximum permissible current (calculated in step 3). At each step observe the reading of V3. Is it less than the no load voltage? If so then can you reason it? Does the maximum rated current through either T1 or T2 (in which ever it happens to arrive earlier) flow beyond the rated power of the load (that is the sum of the power rating of usage of T1 and T2)? If so then can you reason it?

5. Note the readings in following tabular form.

<table>
<thead>
<tr>
<th>Step (Load)</th>
<th>A1</th>
<th>W1</th>
<th>A2</th>
<th>W2</th>
<th>A3</th>
<th>V3</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
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</tbody>
</table>

Table 1: Load test with two transformers in parallel

6. Note the multiplication factor of the Wattmeter. Do not go beyond the rated current.

7. Switch off the system as explained above.

8. Based on V3’s reading at maximum rated current, determine the maximum power at the output at full load. Determine the theoretical output voltage at full load based on the impedance as obtained from the short circuit test of the two transformers.

9. Also determine the corresponding voltage regulation.

Short Circuit Test of Single Phase Transformer:

1. Make the connections as shown in figure. The secondary will be short circuited. Make sure the secondary is the Low voltage side (why?).

2. Determine the rated current which would flow in the primary (the high voltage side) depending on the rated KVA according to transformer usage.

3. Close the DPST switch and gradually increase the Autotransformer voltage till A1 reads the rated current.
4. Note down the readings of V1, A1 and W1. Note down the multiplication factor of the Wattmeter and proceed to calculate the short circuit parameters of the single phase Transformer.

5. Repeat the above procedure for the other transformer.

Fig2: Circuit connections for short-circuit test

Fig3: Equivalent Circuit
Fig 4: Connection for load test with two transformers in parallel