EXPERIMENT Transformer Equivalent Circuit using DACI

Steady-State Testing and Performance of Single-Phase Transformers

OBJECTIVE

The voltage regulation and efficiency of a distribution system are affected by the electrical and magnetic characteristics of the transformers operating in the network. The design of such a distribution system must consider these effects. This experiment demonstrates the concept of open-circuit and short-circuit testing of transformers. From these tests, it is possible to determine the equivalent circuit of the transformer. The experiment also studies the excitation current, magnetization current, and core-loss current.

REFERENCES


BACKGROUND INFORMATION

The basic theory of transformer operation is adequately explained in Reference 1. For our purposes here we will concentrate on the test methods and the experimental set-up of Figure 2.

Figure 1 shows the traditionally accepted electrical equivalent circuit for a power transformer in steady-state. This particular equivalent circuit’s parameters are referred to side 1. All relevant impedances, voltages, and currents are shown in the figure.
Figure 1: Steady-state equivalent circuit for power transformer.

It is important to note that for a typical power transformer the ratio of the parallel combination of the common leg impedances to the total impedance of either winding will exceed 200. Algebraically, this can be described as

\[
\left| \frac{R_c // X_m}{R_1 + jX_{r1}} \right| > 200
\]

(2.1)

Figure 2 shows the experimental concept for the open-circuit and short-circuit tests.

Figure 2: (a) Instrumentation for open-circuit test. (b) Instrumentation for short-circuit test.
The **open-circuit** test is run at rated voltage and yields the following quantities; 

\[
I_{oc} = \text{exciting current as read by ammeter A.}
\]

\[
V_{oc} = \text{applied voltage as read by voltmeter V.}
\]

\[
P_{oc} = \text{power as measured with wattmeter W.}
\]

\[
R_1 \quad \text{and} \quad X_{\ell_1} \quad \text{are very small values, thus, their voltage drop is minimal. The voltage is small enough for us to assume that the open-circuit voltage } \quad V_{oc} \quad \text{appears across } \quad R_c \quad \text{and} \quad X_m, \quad \text{and that all power } \quad P_{oc} \quad \text{is dissipated by } \quad R_c. \quad \text{Therefore,}
\]

\[
R_c = \frac{V_{oc}}{P_{oc}} \text{ ohms}
\]

(2.2)

The reactance \( X_m \) can be found by determining the reactive part of the test quantities. Thus, the power factor is 

\[
\text{pf} = \frac{P_{oc}}{V_{oc} I_{oc}} \quad Q = \sqrt{S^2 - P^2}
\]

(2.3)

and 

\[
I_m = I_{oc} \sin \left[ \cos^{-1} (pf) \right]
\]

(2.4)

from which 

\[
X_m = \frac{V_{oc}}{I_m} = \frac{V_{oc}^2}{Q_{oc}} \text{ Ohms}
\]

(2.5)
Transformer Model

The **short-circuit** test is run at rated current and provides the following information:

\[ V_{sc} = \text{applied voltage as read by voltmeter } V \]

\[ I_{sc} = \text{input short-circuit current as read by ammeter } A. \]

\[ P_{sc} = \text{input power as read by wattmeter } W \]

Recalling Eq. 2.1, the equivalent impedance seen by the instruments is

\[
Z_{eq} = (R_1 + R_2') + j(X_{\ell_1} + X_{\ell_2}) = R_{eq} + jX_{eq} = \frac{V_{sc}}{I_{sc}}
\]

(2.6)

Since the parallel combination of the common leg impedance is very large, the majority of the input short-circuit current passes through only the winding impedances. Therefore, the core losses are negligible and the following is true:

\[
R_{eq} = \frac{P_{sc}}{I_{sc}^2}
\]

(2.7)

and

\[
X_{eq} = \sqrt{Z_{eg}^2 - R_{eq}^2}
\]

\[
R_1, R_2 = \frac{R_{eq}}{2} \quad X_1, X_2 = \frac{X_{eq}}{2}
\]

(2.8)

In the absence of more definitive information, the components of \( R_{eq} \) and \( X_{eq} \) are split equally between the two sides of the transformer. The power rating of the transformer can be calculated from the rated voltage (Voc) and the rated current (Isc) on the same side of the transformer.

\[
\text{Power rating} = \text{Voc} \times \text{Isc}
\]

This completes the development necessary to derive the steady-state equivalent circuit from the test data.
SUGGESTED PROCEDURE

The transformers used for this experiment are rated 120V-120V, 0.6kVA. There are three of them on each set of wall shelves. The set of windings connected to the source side of the transformer are called primary windings, and those connected to the load are named secondary windings. To achieve a 600 volt-ampere rating, these two sets of main primary and secondary windings must be in parallel. The other two windings are information (instrumentation) windings and are not designed to support a load.

Figure 1 defines the currents that are referred to throughout the experiment.

1. Figure 6 shows the connections for performing the open-circuit and short-circuit tests. Since the turns ratio is 1:1, both tests are done on the same side of the transformer. The open-circuit test is performed at rated voltage (120V), and the short-circuit test is performed at rated current (5 AMPS).
The open circuit and short circuit test both use the 40A connection for the current with DACI.

**OPEN CIRCUIT TEST**
The secondary jumper must be disconnected for the open circuit-test, while applying rated voltage, 120 V, from the Single-Phase AC Source to the primary side of the transformer. Record Power, Current, and Voltage.

<table>
<thead>
<tr>
<th>Voltage OC</th>
<th>Current OC</th>
<th>Power OC</th>
</tr>
</thead>
<tbody>
<tr>
<td>120V</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**SHORT CIRCUIT TEST**
The short-circuit test is run with the secondary jumper connected. SLOWLY increase (the voltage is less than 3.0 Vrms) the Single-Phase AC Source from the zero setting until a 5 AMP reading is achieved on the meter. Allow a little time for the system to stabilize at 5 AMPS and then, record Power, Current, and Voltage.

<table>
<thead>
<tr>
<th>Voltage SC</th>
<th>Current SC</th>
<th>Power SC</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>5A</td>
</tr>
</tbody>
</table>

Add jumper here to short circuit

![Diagram of the test setup](image)
REPORT

Study questions

Explain the concept and procedure for open- and short-circuit testing of transformers.

Open-Circuit Test
This test allowed us to find …… (Continue expanding in your own words, say what you did and why you did it. Include all equations, table, data, plots, and results for this part)

Short-Circuit Test
This test allowed us to find …… (Continue expanding in your own words, say what you did and why you did it. Include all equations, table, data, plots, and results for this part)

Explain why the tests should be performed on the high or low voltage sides as appropriate.

Why did we use the same side in our experiment?

This is to be done in class before you leave the Lab.

Derive the equivalent circuit for the transformer tested during this experiment.
Find $R_c$, $X_m$, $X_1$, $X_2$, $R_1$, $R_2$, $Z_{eq}$, $R_{eq}$, $X_{eq}$, $Q_{sc}$, $Q_{oc}$, power rating, $pf_{oc}$, and $pf_{sc}$. Draw the equivalent circuit.