# TRANSFORMER PARAMETER AND LOSS MEASURMENT

## Introduction

The earliest electric power distribution system was a 120V DC system invented by Thomas Edison to supply power for incandescent lamps in 1882. This power system generated and transmitted at such low voltages that very large currents were necessary to supply significant amounts of power, resulting in large power losses and short transmission ranges. The invention of the transformer and the concurrent development of AC power sources eliminated forever these restrictions on the range and power level of power systems.

A transformer ideally changes one AC voltage level into another voltage level without affecting the actual power supplied, through the action of a magnetic field. It consists of two or more coils of wire wrapped around a common ferromagnetic core. The only connection between the coils is the common magnetic flux present within the core. If a transformer steps up the voltage level of a circuit, it must decrease its current to keep the power into the device equal to the power out of it. Therefore, AC electric power can be generated at one central location, its voltage stepped up for transmission over long distances at very low losses, and its voltage stepped down again for final use. Since the transmission losses in the lines of a power system are proportional to the square of the current in the lines, raising the transmission voltage and reducing the resulting transmission currents by a factor of 10 with transformers, reduces power transmission losses by a factor of 100.

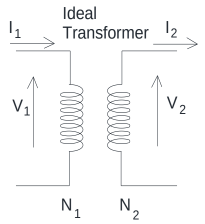


Figure 1

The symbol for an ideal transformer is show in figure 1. The relationships between voltage and current are

$$\frac{V_1}{V_2} = \frac{N_1}{N_2}$$
$$N_1 I_1 = N_2 I_2$$

Real transformers can deviate significantly from their ideal counterparts. In a real transformer the winding resistances are not zero, the magnetic coupling between the coils is not perfect and the reluctance of the core is not zero. It is possible to represent the real transformer by an equivalent circuit consisting of an ideal transformer together with other elements which account for the deviations from ideal. One of the most widely used linear, lumped parameter equivalent circuit models for a power transformer is shown in figure 2. Refer to reference 1 for a detailed development of this model. In this experiment the parameter values of this model for a particular transformer will be determined by measurements.

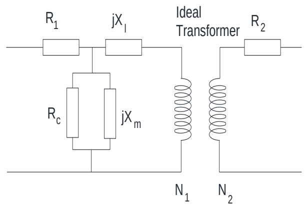


Fig 2 Power Transformer Equivalent Circuit

In the model shown in figure 2 $R_1$ represents the primary winding resistance, $R_2$ the secondary winding resistance, $X_l$ the leakage reactance referred to the primary side, $X_m$ the magnetising reactance referred to the primary side and $R_c$ is a resistance to represent the total core loss both eddy current and hysteresis.

The methods used in this experiment are commonly referred to the open circuit and short circuit tests of a transformer. These methods are used by transformer manufacurers to verify the design and also by users to satisfy themselves that the transformer meeds the specifications.

A wattmeter, as its name suggests, is an instrument for measuring power. In an electrical circuit

$$P = v(t) \times i(t)$$

Therefore a wattmeter has to multiply a voltage by a current and this will be a function of time. In ac circuits where the voltage is sinusional and the current is sinusoidal but the two may not be in phase the frequency of the power will be twice that of the current and voltage. The average power (averaged over a second or so) is generally more useful. Commercial wattmeters do the multiplication and averaging together. Therefore it is entirely possible to have high current and high voltage applied to the wattmeter and the instrument indicating zero or a negative value. The voltage sensor and the current sensor of the instrument will have a maximum rating and it is important that this is not exceeded. It is essential to use a voltmeter and an ammeter to ensure that the wattmeter voltage and current sensors are not overloaded.

In electrical circuits it is common to encounter wide ranges of currents and voltages. To ensure that general purpose laboratory instruments can be used very accurate transformers can be used to scale the actual circuit voltage to suit the measuring instrument. For example if it is required to measure a voltage in the 1kV range an accurate 10:1 (ideal) transformer may be used. The voltage on the secondary side being 1/10 the

primary voltage and the instrument reading is simply multiplied by 10.
Another transformer arrangement is know as a current transformer. This utilises the current constraing of the ideal transformer

$$N_1 I_1 = N_2 I_2$$

Such accurate transformers are know as current transformers (CT's) and are generally used in circuits carrying high currents. The ratio (N1/N2) for a current transformer is usually specifiend as the rated primay current/rated secondary current. Very ofter the primay winding of the transformer is just 1 turn threaded through the core. It is important to note that CT's should always be operated with the secondary effectively short circuited or connected to a low impedance device. An ammeter or the current coil of a wattmeter is a low impedance device.

## Reference

'Electrical Machines' J.D Edwards, pp 97-99.

## Ojectives

The objective of this experiment is to determine the five parameters of the approximate equivalent circuit of the real welding transformer.

## Apparatus

* Welding transformer, 220/55 V, 5kVA
* Wattmeter, 5 A, 220 V
* Ammeters, 5A MI, 25A MI
* Voltmeters, MI 300 V
* Current Transformers, 120/5 A 50/5 A

## Procedure

## 1 DC Winding resistance

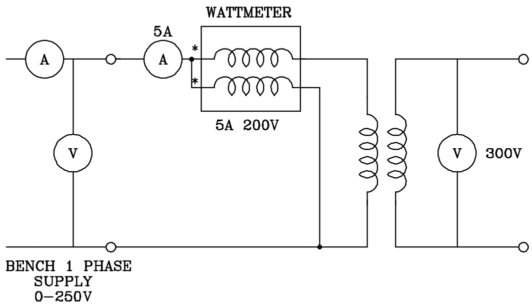
The winding resistance is measured by applying a dc voltage and measuring the current. Since the current is dc, after a short time the voltage will just be that due to the winding resistance; inductive effects and coupling between the winding will be eliminated.

The low resistances require a four terminal measurement which eliminates the effects of constact resistance. The demonstrator will apply circa 10A. The dc voltage will be measured with a digital voltmeter and R=V/I.

## 2 Open-circuit test

The open circuit test is performed at rated voltage. This should be determined from the nameplate of the transformer. The primary terminals, with additional 4mm sockets for voltage leads, are located inside the metal enclosure. Set the circuit up as shown in Fig. 3.

**Fig. 3**




Apply rated voltage. Measure:

| | | |
|---|---|---|
| $V_1$ | = | 220V |
| $V_2$ | = | V |
| $I_1$ | = | A |
| P | = | W |

From this data probably the most important parameter of any transformer can be determined ie the turns ratio N1/N2 = V1/V2.

In this test it is reasonable to assume since the primary current is low compared to the rated current then the voltage drop across the primary winding resistance of the equivalent circuit is negligible. In this case it can be assumed that the equivalent circuit can be approximated by that show in figure 4.

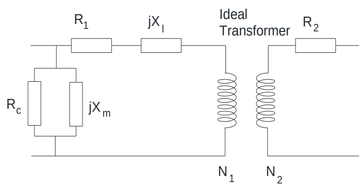



Figure 4

The current flowing through $R_1$, $X_l$ and $R_2$ will be zero and therefore the effective equivalent of the open circuit transformer is the parallel combination of $R_c$ and $X_m$.

$$P = \frac{V^2}{R_c}$$

$$\dot{I} = \frac{V}{R_c} + \frac{V}{jX_m}$$

$$|\dot{I}| = \frac{V}{R_C X_m}\sqrt{R_c^2 + X_m^2}$$

The magniture of I is measured on the ammeter and then the power, current and voltage measurements enable $R_c$, and $X_m$ to be determined.

## 3 Short circuit test

This test is usually done at rated current. You should determine rated primary and secondary currents from the rated kVA (5kVA) of the transformer. Set up the circuit as shown in figure 5. After your TA has checked your circuit make sure the adjustable voltage is set to minimum and then switch on. Slowly increase the voltage while monitoring the current. Bring the current up to approximately the rated value. Use appropriately sized cable to carry the current.

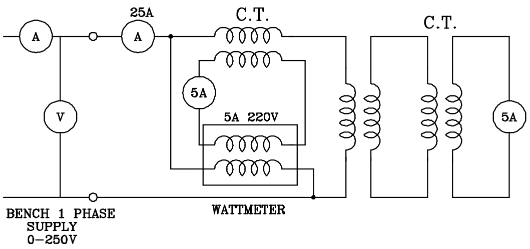



**Fig. 5**

*Using Current Transformers.*

*The primary windings of current transformers are usually marked with capital letters, and that range selection usually involves changing the primary turns, the secondary winding being without taps. The higher current ranges are got by threading cable through the core aperture to form a specified number of linkages. The most usual current rating for CT secondaries is 5A. 1A secondaries are found when cable runs to instruments are long.*

In this configuration since the terminal voltage is low compared to the rated value the current flowing in the shunt components of the equivalent circuit $R_c$ and $X_m$ will be relatively small. The effective equivalent circuit becomes that shown in figure 6.

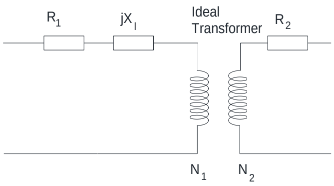



Figure 6

Measure

| | | | |
|---|---|---|---|
| | $I_1$ rated | = | A |
| | $I_2$ | = | A |
| | $V_1$ | = | V |
| and | P | = | W |

N1/N2 = I2/I1. This should compare well with the turns ratio determined in the open circuit test.

$$P = I_1^2 R_1 + I_2^2 R_2$$

or if $R_2$ is referred to the primary side then

$$P = \left( R_1 + \left(\frac{N_1}{N_2}\right)^2 R_2 \right) I_1^2$$

Let

$$R_w = R_1 + \left(\frac{N_1}{N_2}\right)^2 R_2$$

where$R_w$ the winding resistance referred to the primary side.

And then

$$P = R_w I_1^2$$

This equation allows $R_w$to be determined as P and $I_1$ are know from the measurements.

$$\dot{V} = R_w \dot{I}_1 + jX_l \dot{I}_1$$

Rearanging

$$\dot{I}_1 = \frac{\dot{V}}{R_w + jX_l}$$

Therefore

$$|\dot{I}_1| = \frac{V}{\sqrt{R_w^2 + X_l^2}}$$

$X_l$can now be determined as it is the only unknown in this equation.

Do not forget to allow for CT multiplication factor!

**Tidy up all leads and switch off bench supply and instruments after experiment.**


Jeremiah O'Dwyer
January, 2012.