Transformer testing examples for the Fluke Norma 5000 Power Analyzer

Application Note

The Fluke Norma 5000 Power Analyzer can perform a huge number of measurement tasks. One key task is transformer testing, for making primary offline analyses for both laboratory and field tests. The Norma 5000 has the great advantage of needing no extra circuits to do this, requiring only a few settings to be made. With its total basic accuracy for power measurement from 0.1% (reading and range), it is one of the world's most advanced units.

The Norma 5000 is available with several measurement channels. For transformer testing, the PP64 measurement channel provides a distinct advantage. When working on transformers with very low power factors, the PP51 channel adds a higher sample rate (1MHz), which delivers best results for power measurements.

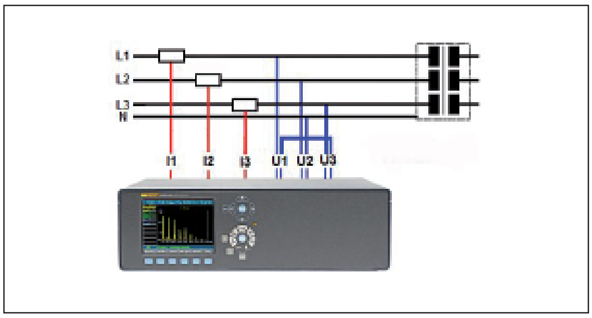
Measurement tasks summary

An important parameter for transformer manufacturers is the efficiency. This may seem simple to measure (i.e. Power In vs. Power Out), but other variables are involved. Although Core Losses, Copper Losses, and Leakage Reactance can have very small values, they affect the efficiency – and can also provide valuable information to the manufacturer.

The following transformer measurement tasks can be performed with the Fluke Norma 5000 Power Analyzer:

- Core (iron no load) losses (open circuit test) ⇒ Offline
- Copper Losses (short circuit test) ⇒ Offline
- Efficiency (= load losses) ⇒ Online or Offline
- Turns ration test ⇒ Offline
- Temperature ⇒ Offline
- Winding resistance ⇒ Offline
- Excitation current ⇒ Offline
- Impedance voltage ⇒ Offline
- Harmonic analyses ⇒ Online or Offline

Normally, all the transformer tests (loss measurement tasks) take place "offline" in the laboratory area.



Fluke Norma 5000:

- Efficiency (load losses) of single- and three-phase systems
- Translation ratio of single- and three-phase systems
- Harmonic analyses of single- and three-phase systems

Transformer equivalent circuit diagram

Figure 1 shows an equivalent circuit of a transformer including losses and leakage reactance (this is what the power source actually "sees" as it looks at a loaded transformer). The parallel branch that is composed of a resistor and an inductor does not really exist, but the core loss current and the magnetizing current act as though it does. The resistance represents the Core Losses, while magnetizing the core requires the inductance.

The sources "see" a resistance which consists of the primary wire resistance plus the equivalent secondary resistance. Since the secondary resistance has been "referred" to the primary, the source "sees" the secondary resistance times the turns ratio squared. The inductance (reactance) shown is the leakage inductance of the primary plus the "referred" secondary leakage inductance. Finally, there is the load, which is also "referred" to the primary and is equal to the load impedance times the turns ratio squared.

It is important to note that the diagrams show single-phase transformers, but all tests can also be performed on three-phase transformers!

The following pages give some examples of typical tests performed by manufacturers to determine the values discussed above. Each will give a brief explanation of the test, a diagram for connecting the Fluke Norma Power Analyzer, some of the important variables that can be determined using the Norma 5000, and advantages of the unit. We will also discuss examples of other tests.

Transformer tests: open circuit test

While transformers are ideally very efficient, there are some small losses that need to be determined. These include **Core Losses**, which can be determined by an **Open Circuit Test (No-Load Test)**. The core loss is proportional to the magnetic field, which is proportional to the applied voltage. By applying the full voltage to the primary while leaving the secondary open, you establish the field in the core. The field is equal to the field that would be present if you loaded the secondary. So, the losses are the same as they would be in a loaded transformer.

Using the connection in Figure 2, the Fluke Norma 5000 Power Analyzer can be used during this test to determine I1, U1, P1, Pc1, fU1, Phase Angle and Power factor (λ).

Pc1 is the corrected power, which is needed when the input signal to the transformer is not sinusoidal. **The Fluke Norma 5000 corrects the measured power based on the deviation of the form factor from the form factor of a sine wave.** The actual formula is:

$$P_{c1} = \frac{P}{0{,}5 + 0{,}5 * \left(\frac{U_{rms}}{U_{rect} * 1{,}1107}\right)^2} \qquad P_t = P_{c1} + P_{c2} + P_{c3}$$

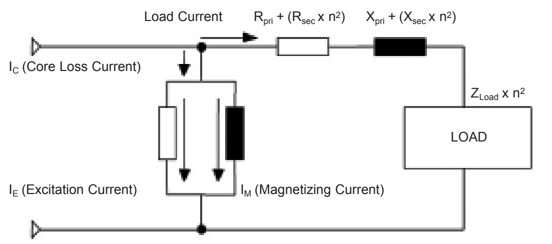


Figure 1: Equivalent Circuit

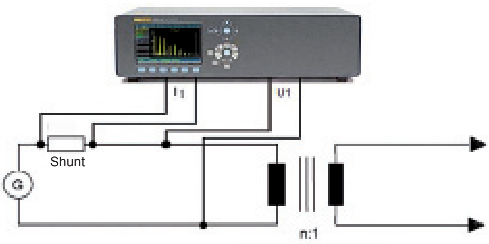


Figure 2: Open Circuit Test

Measurement execution
Connect the Norma 5000 into circuit as shown in Figure 2. Adjust the signal source with nominal current (measured at channel I1); the displayed power P1 is the value of the Core Losses (Plfe).

Measurement equipment
(Accessories depending on power of transformer system) Single-phase transformer: 1x Fluke Norma 5000 FLUKE-N5K 3PP64I 3x measurement channel PP64

Transformer tests: short-circuit test

Also of interest to transformer manufacturers are **Copper Losses**, which are defined in simple terms as Power Losses that are produced by primary and secondary coil resistances. Unlike Core Losses, which remain constant with load, Copper Losses (resistances) and leakage reactance vary with the load. To determine these variables, it is necessary to perform a **Short-Circuit Test**.

First, the transformer secondary side is shorted. A variable voltage is applied to the primary, starting at zero and gradually increasing. At approximately 5% of rated voltage, rated currents will flow in both primary a secondary coils. Since the voltage is at only 5% of rating, the core flux will also only be 5% of rating, so the Core Losses are insignificant.

Using the connection in Figure 3, the Fluke Norma 5000 Power Analyzer can be used during this test to determine the following variables: I1, U1, P1, Z (impedance), Power factor and Phase Angle.

Measurement execution
Connect the Norma 5000 into circuit as shown in Figure 3. Adjust the signal source with nominal voltage (measured at channel U1); the displayed power P1 is the value of the Copper Losses (Plco).

Measurement equipment
Three-phase transformer:
1x Fluke Norma 5000 FLUKE-N5K 3PP64I
3x measurement channel PP64
(Accessories depending on power of transformer system)

Transformer tests: efficiency determination (direct)

The two previous tests are always used on large high efficiency transformers to achieve the required accuracy. This method is also called **loss separation**. Small transformers can use **direct efficiency determination** by measuring the input and output powers.

The connection in Figure 4 can directly measure input power and output power. From these variables, it is possible to **calculate the Efficiency and the Power Losses** using the formulae:

Efficiency FEF [%] = P2 / P1 x 100

Power Loss FPL [W] = P1 - P2

Measurement execution
Connect the Norma 5000 into circuit as shown in Figure 4. You can see the primary power (P1) and the secondary power (P2) on the instrument. The formula above will give you the efficiency of the tested system.

Measurement equipment
Three-phase transformer:
1x Fluke Norma 5000 FLUKE-N5K 6PP64I
6x measurement channel PP64
(Accessories depending on power of transformer system)

Transformer tests: turns ratio test

The voltage applied to the primary coil of the transformer divided by the number of turns of the coil is equal to the volts per turn. The volts per turn of the secondary are equal to the volts per turn of the primary. The primary voltage divided by the secondary voltage is equal to the **Voltage Ratio**. This **Voltage Ratio** in **no-load condition** and the **fundamental voltages compared** correspond to the **turns ratio**. A similar relationship exists between the primary and secondary current, but these are indirectly proportional.

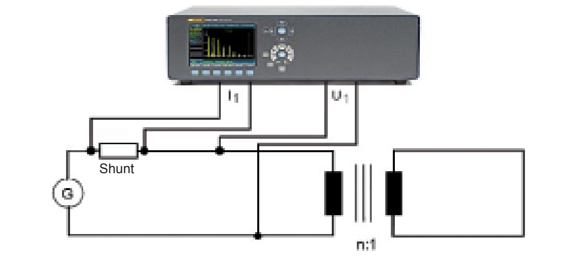


Figure 3: Short-Circuit Test

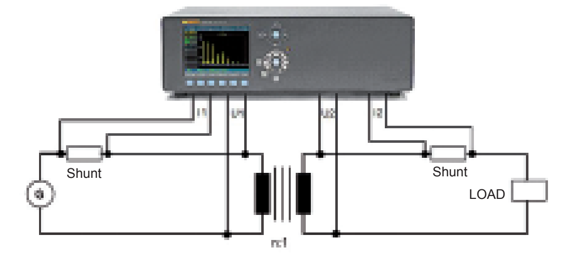


Figure 4: Direct Efficiency Measurement

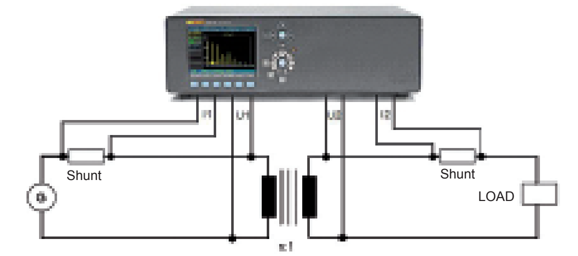


Figure 5: Turn Radio test

Using the connections in Figure 5 and the DFT display (numeric function), the user can determine the fundamental (H01) values of U1, U2, I1 and I2. From these values, the **Turns Ratio** can be determined using **F1 = U1H01 / U2H01**. This can also be done for a three-phase transformer by measuring all six fundamental voltages **(F1 = U1H01 / U4H01)**.

Measurement execution
Connect the Norma 5000 into circuit as shown in Figure 5. You can see the primary voltage (U1H01) and the secondary voltage (U2H01) on the instrument. The formula above will give the turns ratio of the transformer.

Measurement equipment
Three-phase transformer: 1x Fluke Norma 5000 FLUKE-N5K 6PP64I
6x measurement channel PP64
(Accessories depending on power of transformer system)

Transformer tests: harmonics analyses

A manufacturer may also be interested in the harmonics that are generated on the line by the transformer. It is necessary to investigate the influence of the transformer on line supply and on other consumers of the power. **This type of analysis is also important because harmonic distortion is directly related to heating effects and disturbance of other consumers.**

Using the connections in Figure 6, the Norma 5000 can measure the individual harmonics up to the 40th order and calculate the Total Harmonic Distortion (THD) in percent. Users can examine the current, voltage, and power harmonics amplitude and their phase shift for the fundamental. Additionally, the spectrum for all primary values up to the 40th order can be computed simultaneously. The output can be selected numerically or graphically for the display as well as the printer.

Measurement execution
Connect the Norma 5000 into circuit as shown in Figure 6. You can see the harmonic distortion (U1thd and I1thd) directly on the instrument. You can also use the FFT function to analyze the complete spectrum of the test system.

Measurement equipment
Three-phase transformer:
1x Fluke Norma 5000 FLUKE-N5K 6PP64I
6x measurement channel PP64
(Accessories depending on power of transformer system)

Additional information: effects of frequency on efficiency

Because of the reactance found in a transformer, the frequency of the signal into a transformer can affect the efficiency. From the equations XC = 1/2 πfc and XL = 2πfL, it can be seen that the frequency does affect the reactance of the transformer, which can affect the losses associated with these values. Users can measure the **power in vs. power out at different frequencies** to determine the effect.

Using the connections in Figure 7, it is possible to measure U1, U2, I1, I2, P1, P2 and f. From this, you can compare the efficiencies at different frequencies.
Measurement execution
Do the same as with the efficiency test, and compare the results at different frequencies.

Measurement equipment
Three-phase transformer: 1x Fluke Norma 5000 FLUKE-N5K 6PP64I
6x measurement channel PP64
(Accessories depending on power of transformer system)

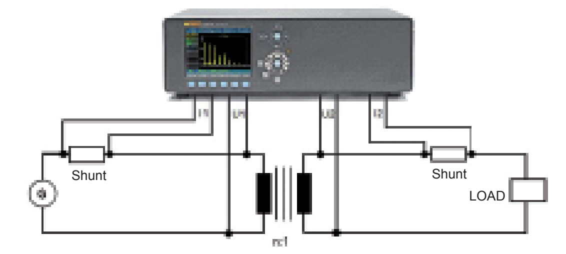


Figure 6: Harmonic Analyses

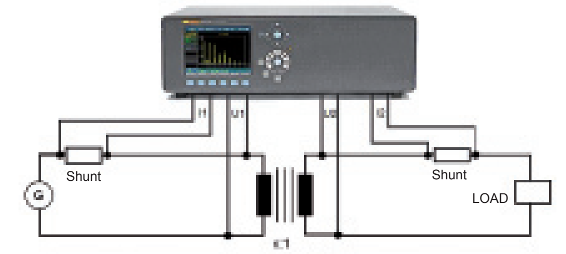


Figure 7: Measuring Frequency Effects

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